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Written object naming, spelling to dictation, and immediate copying: Different tasks, different pathways?

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We report an investigation of cross-task comparisons of handwritten latencies in written object naming, spelling to dictation, and immediate copying. In three separate sessions, adults had to write down a list of concrete nouns from their corresponding pictures (written naming), from their spoken (spelling to dictation) and from their visual presentation (immediate copying). Linear mixed models without random slopes were performed on the latencies in order to study and compare within-task fixed effects. By-participants random slopes were then included to investigate individual differences within and across tasks. Overall, the findings suggest that written naming, spelling to dictation, and copying all involve a lexical pathway, but that written naming relies on this pathway more than the other two tasks do. Only spelling to dictation strongly involves a nonlexical pathway. Finally, the analyses performed at the level of participants indicate that, depending on the type of task, the slower participants are more or less influenced by certain psycholinguistic variables.

Keywords: Written naming; Spelling to dictation; Copying; Individual differences; Word frequency; Phonology-to-orthography consistency.

Adults are able to produce the spellings of words from different types of input: from ideas they wish to express on a sheet of paper, from objects they perceive in their immediate environment, or from words they have just heard or seen. Any theory of spelling word production must account for how orthographic representations are derived to produce a series of fingerpresses on an iPad or a written trace on a sheet of paper from any type of input (e.g., ideas, objects, or words). In the present study, we focused on one output modality—handwriting—and addressed the general issue of how the spellings of the words that we know are derived from three different types of input: pictures, spoken words, and visually presented words. Researchers who have investigated the spelling performance of healthy adults or of patients have mainly used three tasks—written naming, spelling to dictation, and immediate copying—which correspond to different ways of producing the spelling of words. One general issue that we have addressed in the present study is the extent to which these three spelling tasks rely on similar or different processing pathways. Before we spell out the more specific

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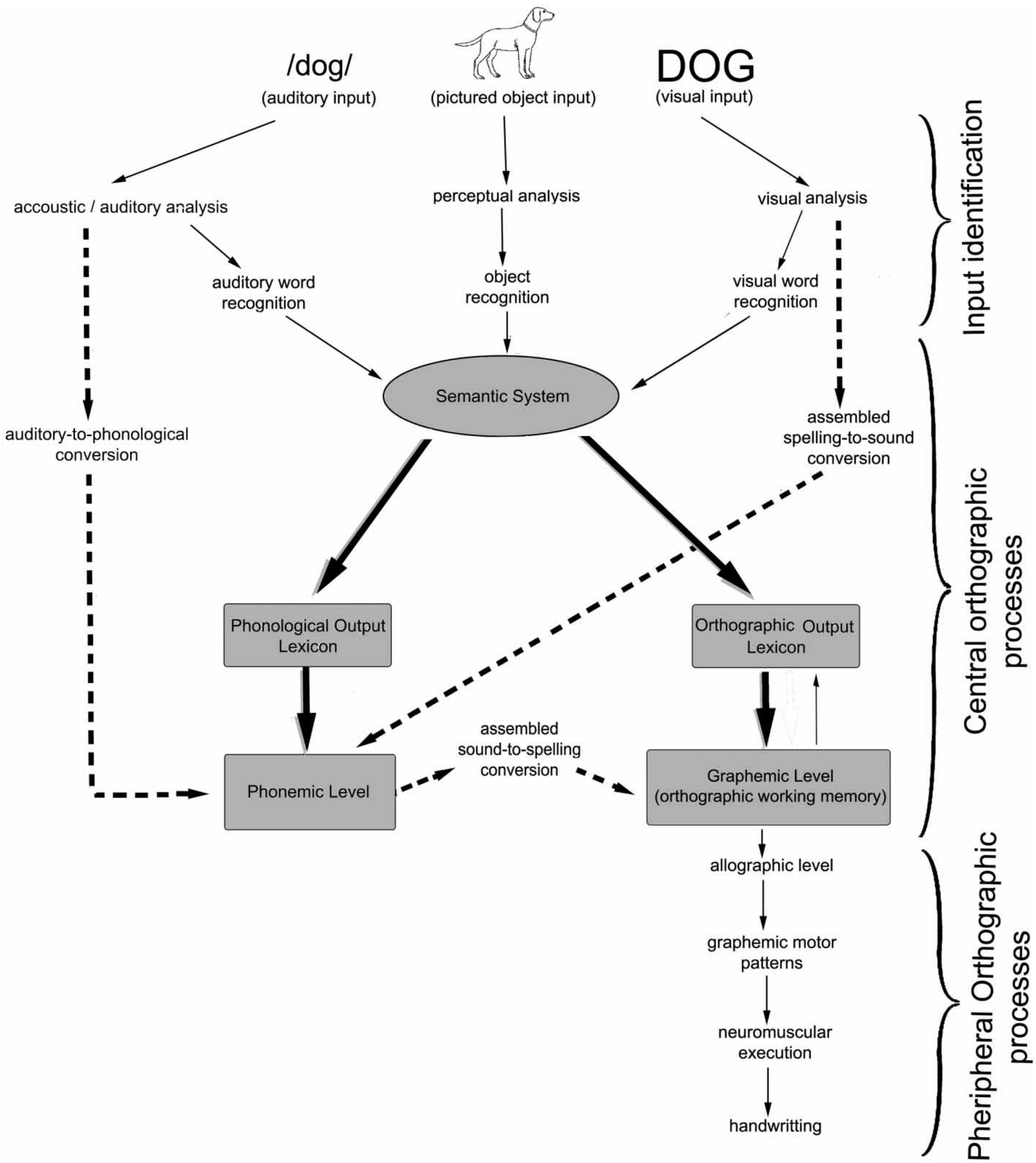

Figure 1. *General theoretical framework for understanding the component processes involved in written object naming, spelling to dictation, and immediate copying (the components belonging to the lexical pathway are presented against a grey background, and the components relating to the nonlexical pathway are shown in bold dotted lines).*

issues addressed in our study, together with the general methodological approach pursued, we will sketch a general model of adult spelling word production. This theoretical framework will help to clarify the different specific predictions examined in our research.

Figure 1 provides a general theoretical framework for understanding the component processes involved in written object naming, spelling to dictation, and immediate copying. This framework incorporates various theoretical proposals taken from certain studies of written naming (Bonin, Chalard, Méot, & Fayol, 2002; Bonin, Peereman, & Fayol, 2001; Bonin, Roux, & Barry, 2011; Bonin, Roux, Barry, & Canell, 2012; Caramazza, 1997; Miceli, 2001), spelling to dictation (Bonin, Collay, Fayol, & Méot, 2005; Delattre, Bonin, & Barry, 2006; Rapp, Epstein, & Tainturier, 2002; Tainturier & Rapp, 2001), and immediate copying (e.g., Cuetos, 1991; Kandel, Peereman, Grosjacques, & Fayol, 2011; Roux, McKeeff, Grosjacques, Afonso, & Kandel, 2013). In this framework, there are components that are dedicated to a given task only. These are object recognition in object naming, auditory word recognition in spelling to dictation, and visual word recognition in immediate copying (Figure 1). These components belong to a stage that we shall refer to as *input identification*. There are other components that are shared by the three tasks (e.g., orthographic output lexicon, sublexical conversion processes, orthographic working memory). These belong to a stage of *central orthographic processes*. Finally, from the orthographic working memory, there are processes dedicated to the planning and execution of the handwriting trace (i.e., allographic processes, graphomotor planification, and execution processes). These processes correspond to the stage of *peripherical orthographic processes*.[1]

In alphabetic languages such as English or French, where the relationships between sound and orthographic sublexical units are not systematic (Peereman & Content, 1999), it is necessary to hypothesize that, in order to spell correctly, access to the lexical orthographic representations must be made possible from an orthographic output lexicon in all types of spelling task (Purcell, Turkeltaub, Eden, & Rapp, 2011; Tainturier & Rapp, 2001). In effect, the spelling of the great majority of words in French or in English cannot be produced correctly by the sole operation of a component that uses sublexical sound–spelling correspondences (Kreiner, & Gough, 1990; Véronis, 1988). Indeed, there are so many inconsistencies in the mappings between sublexical sound and spelling units in these orthographic systems that a spelling system equipped with only a kind of rule-based mechanism would render the spelling of a large number of words hazardous. To illustrate, the /aR/ rime unit in French can be spelled in at least three different ways, the most frequent rendering being "are" and the next two most frequent being "ar" and "ard", both of which have similar consistency scores. A rule-base mechanism would, for instance, take the /ar/ sublexical unit as input, apply the most frequent rime–body association, and deliver the orthographic rendering "are" (as in "gare", meaning station). But how would such a system permit the production of the French words "dard" or "bar" (meaning sting and bar, respectively)? That is why, as shown in Figure 1, most views of word spelling assume that two processing pathways, and not only one, are available to derive the spelling of words (Purcell et al., 2011; Tainturier & Rapp, 2001). Within the lexical pathway, orthographic codes are retrieved from the mental lexicon, whereas the nonlexical pathway involves the operation of sublexical conversion procedures. However, the respective roles of the lexical and nonlexical pathways have not always been clearly distinguished. The primary goal of the present study was therefore to shed light on the contribution of these two pathways in spelling tasks involving written naming, spelling to dictation, and copying. Although nonlexical processing is included in the general cognitive architecture of spelling depicted in Figure 1 for each spelling task, several studies (reviewed below) on both healthy adults and patients suggest, without directly testing, that the involvement of the

[1]The possibility of nonsemantically mediated lexical routes—that is, "direct" lexical routes—has been put forward in the literature (see Hillis, 2001) for both spelling to dictation (a direct link from the auditory word recognition system to the phonological output lexicon) and copying (a direct link from visual word recognition system to the orthographic output lexicon). It is also possible that visually presented stimuli might be copied by means of visual processes only, without the involvement of visual word recognition or phonological conversion. However, to avoid overcomplicating the model in Figure 1, we did not include these links. Finally, since to date there is no evidence in support of the existence of lexical links between the phonological and orthographic output lexicons (Bonin, Peereman, & Fayol, 2001), these bidirectional links are also not included in Figure 1.

nonlexical processing pathway might vary in the online production of words in healthy adults as a function of spelling task.

In all tasks, the orthographic representations of the to-be-produced items can potentially be retrieved from semantic code activation (Figure 1). However, as far as written naming is concerned, the involvement of semantics is obligatory since object recognition units do not contact orthographic representations directly in the orthographic output lexicon (Bonin et al., 2012). Importantly, there is no nonlexical processing pathway starting either from the input identification stage or from the semantic system. In both spelling to dictation and immediate copying, although orthographic codes can be retrieved from semantics, there are also nonlexical routes that permit the computation of orthographic codes by means of sublexical conversion processes. In spelling to dictation, it has been assumed that phoneme-to-grapheme units are used to provide plausible spellings for inconsistent words and correct spellings for consistent words (Tainturier & Rapp, 2001). Importantly, even in written naming, it has sometimes been assumed that a phoneme-to-grapheme assembly route plays a role in the selection of orthographic codes (Bonin, Peereman, & Fayol, 2001; Miceli, Benvegnù, Capasso, & Caramazza, 1997; Miceli, Capasso, & Caramazza, 1999). As shown in Figure 1, semantic codes are able to simultaneously activate lexical representations in both the orthographic and the phonological output lexicons. The lexical representations in the phonological output lexicon activate, in turn, the corresponding individual phonemes at the phonemic level, and these can be converted to individual graphemes by means of a sound-to-spelling conversion procedure.

In all tasks, the outputs of the lexical and assembled spelling routes converge at a common graphemic level. This has often been referred to as the graphemic output buffer in the past (e.g., Caramazza, Miceli, Villa, & Romani, 1987), but more recently, it has been termed the "orthographic working memory" (Purcell et al., 2011). The motor output processes that drive handwriting operate from this graphemic level. In Ellis's (1982) view, graphemic representations pass through three major "stages" in order to be executed in handwriting. First, an *allographic* code is selected for each letter and specifies whether it is to be produced in upper or lower case (and in printed or cursive writing). Second, allographic codes access graphemic motor patterns that specify the sequence, direction, and relative size of letter strokes. Third, graphemic motor patterns undergo neuromuscular execution that determines the scale (or absolute size) and power of the strokes used to produce writing.

Empirical studies of the word frequency and phonology-to-orthography consistency variables in written naming, spelling to dictation, and copying

In spoken word production, word frequency effects have long been taken as a genuine index of the retrieval of word forms in a phonological output lexicon (e.g., Jescheniak & Levelt, 1994; Mädebach, Jescheniak, Oppermann, & Schriefers, 2011). In written naming, object names must be retrieved from semantic codes within an orthographic output lexicon in which word forms are stored. By analogy with spoken word production, word frequency effects have been assumed to index orthographic word-form retrieval in written naming, and several studies have reported word frequency effects in written object naming (e.g., Bonin et al., 2012). One issue that has been widely debated is the question of distinguishing between word frequency effects and age-of-acquisition effects in word production (e.g., Bonin, Fayol, & Chalard, 2001). There is now general agreement among researchers that the two variables have a reliable influence on object naming performance (Johnston & Barry, 2006). One debated issue has been to determine whether word frequency effects in written naming are phonological or orthographic in nature in the light of the links that exist between orthographic and phonological representations (see Figure 1). Indeed, the existence of a direct route from semantics to orthographic word-form representations has been denied by the proponents of obligatory (sublexical) phonological mediation

(Luria, 1970). Analyses of the spelling and naming performance of both patients (e.g., Rapp, Benzing, & Caramazza, 1997) and healthy adults (e.g., Bonin, Fayol, & Gombert, 1997; Bonin, Fayol, & Peereman, 1998) have provided evidence for the hypothesis that orthographic representation can be retrieved directly on the basis of semantic codes—that is, the orthographic autonomy hypothesis (Miceli & Capasso, 1997; Rapp et al., 1997). However, the orthographic autonomy hypothesis does not preclude the involvement of phonological codes in orthographic encoding (Miceli et al., 1999). Indeed, certain studies have provided evidence for the involvement of phonology in written naming (e.g., Bonin, Peereman et al., 2001; Damian, Dorjee, & Stadthagen-Gonzalez, 2011; Damian & Qu, 2013; Qu, Damian, Zhang, & Zhu, 2011). However, the extent to which sublexical phonological codes contribute to orthographic encoding is an issue that still deserves further investigation. To index the contribution of phonology in writing, Bonin, Peereman et al., (2001) selected words that varied on phonology-to-orthography (PO) consistency. PO consistency is a measure of the ambiguity of sound-to-spelling mappings. For instance, phoneme–grapheme consistency takes into account both the frequency with which a particular phoneme is associated with a particular grapheme and the overall frequency of the grapheme, whatever its pronunciation. When the phoneme is always associated with the same grapheme, the ratio is equal to 1. When multiple associations exist, the ratio is less than 1. PO consistency values vary between 0 and 1. Bonin, Peereman et al., (2001) found that inconsistency defined at the sublexical level of rime units had no reliable effect on latencies, whereas PO consistency effects were reliably found when consistency was defined at the level of onset units. The Bonin, Peereman et al., (2001) study suggests therefore that sublexical phonology plays a role in written naming (for further evidence in favour of an involvement of phonology in written production, see Afonso & Álvarez, 2012; Damian et al., 2011; Damian & Qu, 2013; Qu et al., 2011). However, using the picture–picture interference paradigm, Roux and Bonin (2012) recently failed to find a contribution of phonology in orthographic encoding in written naming (see also Bonin et al., 1997; Bonin, Fayol, & Gombert, 1998).

Turning to the spelling-to-dictation task, strong PO consistency and word frequency effects have been found (e.g., Bonin & Méot, 2002; Bonin, Peereman et al., 2001; Delattre et al., 2006). The influence of word frequency has been unambiguously ascribed to the lexical route, whereas the impact of PO consistency has been taken to indicate the involvement of the nonlexical route (Bonin et al., 2005; Bonin, Méot, Millotte, & Barry, 2013). Consistency effects are more consistently found in spelling to dictation than in written naming. For instance, although PO consistency effects have been found in spelling to dictation when consistency was operationalized at the beginning, middle, or end of the words, they occur only when consistency is operationalized at the beginning of words in written naming (Bonin, Peereman et al., 2001). Furthermore, Bonin et al. (2005) have provided evidence for the hypothesis that the nonlexical pathway is mandatory in spelling to dictation.

Finally, the issue concerning the extent to which immediate copying is sensitive to word frequency and to PO consistency variables remains to be investigated since these factors have only been infrequently studied using this task (but see Bonin, Fayol, & Gombert, 1998; Lambert, Alamargot, Larocque, & Caporossi, 2011). Although Bonin, Fayol and Gombert (1998) found an effect of word frequency in copying, the word frequency measures they selected are unfortunately no longer used when designing psycholinguistic experiments in French because they have been found to be insufficiently accurate. The influence of PO consistency could not be assessed by Bonin, Fayol and Peereman (1998) since at the time the study was conducted, PO consistency measures were not available for French words.

To summarize, in order to produce word spellings in written naming, spelling to dictation, and copying, two different processing pathways—lexical and nonlexical—are potentially available.

In the present study, we used linear mixed models to address, for the first time, the extent to which these three spelling tasks rely on these two processing pathways during online handwriting production in healthy adults. The advantage of this approach over the factorial approach is that it makes it possible to take account simultaneously of a potentially large number of variables that are related to spelling performance in the different tasks. Moreover, the influence of a relatively large number of different variables on spelling performance will be investigated using the same set of items within the same participants across three different sessions. Likewise, it will be possible to investigate, across the three tasks, the influence of several important factors on spelling performance. Importantly, and this was a secondary goal of our study, we will also examine the same issues at the level of participants in order to identify individual differences within and across tasks. In visual word recognition, the investigation of individual differences is a recent avenue of research, and this approach has provided considerable information about the differences in the way participants rely on different processes and representations involved in word recognition (Yap, Balota, Sibley, & Ratcliff, 2012). Very recently, individual differences have also been investigated in spelling to dictation (Bonin, Méot et al., 2013). At the theoretical level, our findings will shed light on the degree of involvement of the lexical and nonlexical pathways during the *preparation* of handwriting responses in the three tasks of written naming, spelling to dictation, and immediate copying. In effect, we only took latency measurements into account since the focus of our study was on the preparation of handwriting responses. We acknowledge that the respective contributions of both pathways during the *execution* of written words in each of the three tasks is an issue that also deserves attention and that could be investigated in future studies. This is a very important and novel contribution. At the methodological level, our study will help researchers choose between the three spelling tasks in the light of their reliability in addressing specific issues in adult spelling production.

EXPERIMENTAL STUDY

Method

Participants

Thirty-four psychology students (26 women, mean age = 20 years old) from the University of Bourgogne (Dijon, France) took part in this experiment. All were unaware of the purpose of the experiment and received course credits. They were all native French speakers and had normal or corrected-to-normal vision and no known hearing deficit. None of the participants had any language disorder or movement disorder.

Design

Three tasks—written naming, spelling to dictation, and copying—were used and tested in a within-participants design. In the written naming task, participants were required to write down the name of each presented picture on a computer screen. In spelling to dictation, the object name was spoken aloud, and the participants had to write it down as soon as they understood the spoken word (they were therefore not obliged to wait for the end of the word). Finally, in the immediate copying task, the object name was visually presented in the centre of the screen. Here again, the participants started to write down each presented word as soon as they had read and understood the word. The dependent variables were the latencies (in ms) and the number of errors. Written latencies correspond to the period that elapses from the onset of stimulus presentation (i.e., a picture, or a spoken or a written word) through to movement initiation—that is to say, the start of the handwriting movement for the first letter of the target word. This is defined as the point at which the contact of the pen with the graphic tablet results in a pressure greater than zero. As far as errors are concerned, we analysed orthographic errors and phonologically plausible errors. The former are spelling errors in which the selection of an erroneous orthographic code leads to a nonword that does not read in the same way as the target word (e.g., "error" → "orror"). The latter are errors in which the erroneously selected code leads to a nonword that reads in the same way as the target (e.g., “error” → “errer”).

Stimuli

The experimental stimuli consisted of 300 French nouns of concrete objects. For the picture naming task, we used the corresponding black-and-white line drawings taken from Cycowicz, Friedman, Rothstein, and Snodgrass (1997). For the spelling-to-dictation task, each word was recorded by a female voice. The statistical characteristics of the items are listed in Table 1.

We took into account several characteristics of the words, which can be divided into three broad categories: semantic, lexical, and sublexical characteristics.

Semantic variables. One semantic variable was used: imageability. Imageability is the ease with which a word arouses a mental image and the different measures for the words were taken from Bonin, Méot, Aubert, Malardier, Niedenthal, and Capelle-Toczek (2003), who used a 5-point scale (with 1 = not easily imageable, 5 = very easily imageable).

Lexical variables. In the following analyses, word frequency was operationalized as “cumulative frequency”. Cumulative frequency corresponds to the sum of the *z*-scores associated with two measures of frequency—that is, adult frequency measures taken from Lexique (New et al., 2004) and child frequency taken from Manulex (Lété et al., 2004). As far as Manulex child frequency measures are concerned, the cumulative frequency corresponding to all grades (G1–G5) was used. We did not use age of acquisition (AoA) ratings to investigate age-limited learning effects but instead frequency trajectory because the latter is less correlated with other subjective psycholinguistic variables (see Bonin, Barry, Méot, & Chalard, 2004, for a more detailed discussion). Frequency trajectory was computed as the difference between the *z*-scores associated with the two measures of frequency (Lexique minus Manulex). There are two aspects worthy of note about these scores: (a) We used *z*-scores and not the raw frequencies (log-transformed) because the Lexique and Manulex corpora are not the same, and the use of raw frequencies might have introduced discrepancies between the two measures of word frequency. However, we must stress that the correlations between the *z*-scores and the log-transformed frequency scores were equal to unity; (b) The cumulative frequency and frequency trajectory scores corresponded to the two first factors of the principal component analysis performed on the two frequency measures. As a result, they are uncorrelated, thus permitting more reliable estimations of their effects.

Sublexical variables. PO consistency scores were taken from Manulex-infra (Peereman et al., 2007) and varied between 0 and 1. As described earlier, PO consistency evaluates the ambiguity of sound-to-spelling mappings. When the sound-to-spelling mapping is fully consistent, the ratio is equal to 1, and when there is a high level of ambiguity in the mapping, the ratio is close to 0. We took account of word length, which was operationalized as the number of letters. The number of orthographic neighbours (N) for each word, as defined by Coltheart et al. (1977), was also considered, as was the bigram frequency of the words.

Characteristics of the pictures (and of the spoken words). Since pictures were used for written naming, we also took into account certain important characteristics of the pictures: name agreement and image agreement. Name agreement refers to the degree to which participants agree on a particular name to refer to a picture. It is measured by considering the number of alternative names given to a particular picture across participants. Image agreement refers to the degree to which the mental images formed by participants in response to a picture name match the picture’s appearance. Finally, we took into account the spoken duration of the words that were presented to the participants in the spelling-to-dictation task.

Apparatus

The experiment was conducted with MovAlyzeR® software (Teulings & Caligiuri, 1997). Participants had to write each word with an inking pen on a

Table 1. *Statistical characteristics of the words and the corresponding pictures (and spoken words)*

	Mean	SD	*Min–max*
Semantic variable			
Imageability[a]	4.44	0.41	2.6–5
Lexical variables			
Adult word frequency (log)[b]	1.08	.56	0.02–2.76
Child word frequency (log)[c]	1.49	.64	0.004–2.97
Cumulative frequency	.00	1.88	−4.01–5.33
Frequency trajectory	.00	.67	−2.63–1.97
Sublexical variables			
Initial PO consistency[d]	88.16	25.86	0.30–100
Length	6	1.70	3–12
N	3.71	4.35	0–21
Bigram frequency (log)[d]	3.90	.30	2.23–4.56
Characteristics of the pictures and spoken words			
Name agreement[e]	92.24	11.27	36–100
Image agreement[e]	3.66	.74	1.1–4.9
Acoustic duration (ms)	650.75	147.31	238–1275

Note: PO = phonology-to-orthography; N = number of orthographic and phonological neighbours as defined by Coltheart, Davelaar, Jonasson, and Besner (1977). Acoustic duration (in ms) is for the words used in the spelling task.
[a]Taken from Bonin et al. (2003). [b]Provided by Lexique 2 (New, Pallier, Brysbaert, & Ferrand, 2004). [c]Taken from Manulex (Lété, Sprenger-Charolles, & Colé, 2004). [d]Provided by Manulex-infra (Peereman, Lété, & Sprenger-Charolles, 2007). [e]Taken from Alario and Ferrand (1999).

lined white sheet, which was fixed to the graphic tablet. The graphic tablet (Wacom Intuos 3 A4; sampling frequency 200 Hz, accuracy 0.02 mm) was connected to a computer that monitored the movement the participant executed and recorded the written latencies.

Procedure

The participants were tested individually, seated in a quiet room. They sat in front of the computer screen and the graphic tablet, which was placed horizontally on the table. Participants were instructed to write down the name of the stimulus as quickly (and as accurately) as possible while writing as “naturally” as possible—that is, in cursive handwriting.

Each participant took part in three sessions separated by at least one week. During each session, there were 10 practice trials. Each trial had the following structure: A fixation point (+) was displayed in the middle of the screen for 500 ms, then the stimulus (a picture, a spoken word, or a visual word) was displayed. The stimulus was presented orally (via headphones) for the spelling-to-dictation session, and in the middle of the screen for the written naming (i.e., a picture) and copying (i.e., a word) sessions. The black-and-white pictures or visual word stimuli (presented in upper case: 38 point, Arial font) remained on the screen until the initiation of the first stroke (i.e., the contact of the pen with the graphic tablet). The next trial started 5 s later. The 300 experimental stimuli were randomized and were presented in six blocks that comprised 50 stimuli. The order of administration of the tasks across participants was defined by random permutations of the tasks, with one being administrated per session. Each session lasted about 1 hour.

Results

Scoring of the data

As described in the Design section, written latencies corresponded to the time period from the start of stimulus presentation through to movement initiation—that is, to the contact of the pen with the graphic tablet (pressure > 0). As in previous studies (e.g., Bonin et al., 2002), 29 items were discarded because there were more than 50% of errors in at least one task.[2] Furthermore, two participants were eliminated because they did not complete all three tasks. (The analyses reported below are based on 271 items and 32 participants, given a total of 26,016 potential reaction times, namely 8672 by task.) The different types of errors are reported in Table 2.

As can be seen from Table 2, the participants made more errors in written naming and fewer errors in the copying task. The different number of errors across tasks is primarily due to certain specific features of the tasks, such as the production of alternative names, the occurrence of tip-of-the tongue states, unknown picture names, or unrecognized objects that can only be observed in written naming, as well as the production of words that are incorrectly heard or misunderstood—that is to say, errors that can only occur in spelling to dictation. Finally, among the errors that were observed in each of the three spelling tasks, phonologically plausible errors were far less numerous in copying than in either written naming or spelling to dictation.

In written naming, 18 trials with latencies less than 400 ms and 19 with latencies longer than 3600 ms were set apart. In spelling to dictation, 20 trials with latencies less than 250 ms and 18 with latencies greater than 2000 ms were discarded. In copying, we set apart 17 trials: 7 trials for which the latencies were less than 250 ms and 10 with latencies longer than 1500 ms. Finally, latencies exceeding three standard deviations below or above the participants' means were also discarded. Indeed, we closely adhered to the two-step procedure (thresholds + 3 standard deviations) used by both Balota et al. (2007) and Ferrand et al. (2010). Applying these last two criteria led to the removal of 2.62% of the latencies in written naming, 1.89% in spelling to dictation, and 1.29% in copying. When all sets of criteria were applied, we were left with 7136 trials in picture writing (82.3%), 7778 in spelling to dictation (89.7%), and 8136 in copying (93.8%).

Descriptive statistics, correlations, and linear mixed model analyses

As can be seen from Table 3, the latencies were the longest in written naming and the shortest in copying, with the latencies in spelling to dictation falling between these two values.

The correlations among the variables are reported in Table 4. In written naming, the highest correlations with latencies were observed for imageability and cumulative frequency, with the result that shorter reaction times (RTs) were associated with more imageable and more frequent words. A similar but weaker relationship was found for name agreement, whereas the reverse was observed for frequency trajectory (i.e., longer latencies for ascending trajectories). In spelling to dictation, shorter latencies were found with words having higher initial PO consistency and cumulative frequency scores, whereas longer latencies were found for longer acoustic duration and words with a greater number of letters. The correlations were clearly lower in the copying task. In this task, the highest correlation was between the number of letters and written latencies, with the result that longer latencies were linked to words having more letters. There were also noticeable correlations between cumulative frequency and latencies and between acoustic duration and RTs.

Analyses 1: Within-task linear mixed model analyses without random slopes

A first series of task-specific linear mixed model (LMM) analyses was run with participants and items treated as random factors, which served as the basis for the intercept adjustments in

[2]This elimination procedure was used in order to be able to use a similar pool of items, providing a sufficient numbers of observations, across all analyses. The reasons for excluding these 29 items were as follows: (a) There were technical errors for four words; (b) There were difficulties in naming or recognizing the pictures for 12 items; and (c) There were plausible phonological or orthographic errors for the remaining 13 items. Additional analyses showed that, on both imageability and cumulative frequency, the values for the 12 items that were difficult to name or to recognize were reliably lower than those for the remaining items (271) that were retained for analysis.

Table 2. *Types of error found in written naming, spelling to dictation, and copying*

	PPE	*OE*	*CO*	*TO*	*TECH*			*Total*	*%Tot*
Common for all tasks									
Written naming	227	90	142	1	273			733	8.45
Spelling to dictation	199	110	149		180			638	7.36
Copying	17	96	90	1	225			429	4.95
	IH	*X*	*Hom*	*LexS*	*DKO*	*DKN*	*TOT*		
Task-specific									
Written naming				451	58	38	64	611	7.05
Spelling to dictation	16	42	46	2				106	1.22
Copying				1				1	0.01

Note: PPE = phonologically plausible errors; OE = orthographic errors; CO = crossing out; TO = time-out (>5 s); TECH = technical errors; IH = incorrectly heard; X = word not understood; Hom = homophone substitution; LexS = lexical substitution; DKO = do not know object; DKN = do not know the name; TOT = tip of the tongue; Total = total number of errors; % Tot = percentage of errors among the (8672) trials.

Table 3. *Descriptive statistics of the latencies as a function of the spelling tasks*

	Latency (ms)			
	N	*Min–max*	*Mean*	SD
Written naming	7136	485–2875	1143	346
Spelling to dictation	7778	255–1950	866	219
Copying	8136	270–1425	692	196

Note: N = number of trials.

accordance with the mixed model procedure set out in SPSS 20. The predicted scores were the standardized by-task latencies. We included the same predictors for all tasks—namely, acoustic duration, name and image agreement, imageability, word length defined as the number of letters, bigram frequency (in log), orthographic neighbourhood, initial phoneme-to-grapheme consistency, cumulative frequency, and frequency trajectory. The predictors were all standardized for the entire set of words.

As can be seen from Table 5, the overall explanation was the highest for copying, intermediate for spelling to dictation, and the lowest for written naming.

In written naming, there were reliable effects of word frequency, imageability, name agreement, and image agreement. The directions of these effects were all facilitatory—that is to say that the latencies became shorter as scores increased on the corresponding dimensions (e.g., shorter latencies on items with higher word frequency values). The effect of frequency trajectory was inhibitory, with the result that words having low-to-high frequency trajectory scores took longer to initiate than those having high-to-low scores. Surprisingly, the effect of orthographic length was reliably negative on written naming latencies (the same was true for the bivariate correlation between latencies and orthographic length).

In spelling to dictation, we found that both PO consistency and word frequency had reliable negative/facilitatory effects on spelling latencies: High-frequency words were produced faster than low-frequency words. In addition, high-consistency words were produced faster than low-consistency words. Acoustic duration had an inhibitory effect on the latencies, with the result that the participants took longer to start writing words with longer than with shorter acoustic durations.

The negative effect of number of letters was not reliable at the conventional .05 level (but note that it was marginally significant at $p < .10$). Finally, in immediate copying, two effects were significant: word frequency and number of letters. As in the written naming and spelling-to-dictation tasks, the effect of word frequency was facilitatory. In

Table 4. *Correlations among the variables*

	Imageability	*Cumulative frequency*	*Frequency trajectory*	*Initial consistency*	*Length*	*Orthographic N*	*Bigram frequency*	*Name agreement*	*Image agreement*	*Acoustic duration*
Naming latencies	−.264***	−.221***	.097***	−.046***	−.032**	.046***	.000	−.113***	−.044***	.004
Spelling latencies	−.024*	−.105***	−.016	−.123***	.069***	−.056***	−.026*	−.008	.032**	.154***
Copying latencies	.001	−.051***	.003	−.008	.072***	−.042***	.006	−.009	.016	.050***
Semantic variable										
Imageability		.361***	−.282***	.016	.134*	−.226***	−.026			
Lexical variable										
Cumulative frequency			.000							
Sublexical variables										
Initial consistency		.167**	−.044							
Length		−.261***	−.066	−.067		−.576***	.300***			
N		.203***	.084	.120*						
Bigram frequency		.003	−.004	.001		.085				
Characteristics of the pictures and spoken words										
Name agreement	.125*	.088	−.050	.045	.006	.070	.169**		.117	
Image agreement	.099	−.243***	−.042	−.162**	.002	−.051	−.030			
Acoustic duration	.121*	−.231***	−.035	−.131*	.694***	−.427***	.086	.037	.036	

Note: Correlations were computed over the 271 words for the independent variables while all the trials were used for those between reaction times (RTs) and independent variables (IVs). N = number of orthographic neighbours as defined by Coltheart et al. (1977).
*$p < .05$. **$p < .01$. ***$p < .001$.

Table 5. *Results of the LMM with participants and items treated as random factors*

	Written naming $R^2 = .48$		*Spelling to dictation* $R^2 = .65$		*Copying* $R^2 = .71$	
	b	t	b	t	b	t
Intercept	0.056	0.64	0.020	0.15	0.005	0.03
Semantic variable						
Imageability	−0.157	−4.95***	−0.020	−1.08	0.004	0.49
Lexical variables						
Cumulative frequency	−0.211	−6.62***	−0.064	−3.42***	−0.036	−4.09***
Frequency trajectory	0.055	2.02*	−0.024	−1.52	0.005	0.62
Sublexical variables						
Initial consistency	−0.012	−0.43	−0.099	−6.26***	0.001	0.17
Length	−0.103	−2.30*	−0.049	−1.85	0.081	6.47***
N	0.009	0.27	0.012	0.59	0.007	0.73
Bigram frequency	0.032	1.10	−0.031	−1.77	−0.012	−1.42
Characteristics of the pictures and spoken words						
Name agreement	−0.079	−2.93**	0.002	0.12	−0.005	−0.65
Image agreement	−0.077	−2.77**	0.000	0.02	0.006	0.76
Acoustic duration (ms)	0.056	1.52	0.166	7.68***	−0.002	−0.18

Note: N = Number of orthographic neighbours as defined by Coltheart et al. (1977); LMM = linear mixed model.
$^*p < .05$. $^{**}p < .01$. $^{***}p < .001$.

contrast to written naming and spelling to dictation, the effect of the number of letters was inhibitory, so that it took longer to prepare to write words with more letters than it did words having fewer letters.

Analyses 2: Between-tasks linear mixed model analyses without random slopes

In order to compare the different effects across tasks, we analysed all the latencies obtained in the three spelling tasks using a unique global linear mixed model. The same independent variables as those that had been used in the within-task analyses were included in the model, except for the number of orthographic neighbours and bigram frequency variables, which were not reliable in any of the task-specific models. In order to take account of the different tasks and to compare the effects of the independent variable effects across the tasks, the linear mixed model also included two dummy independent variables that code the three spelling tasks and their interaction terms with other independent variables. The reference category for the tasks was alternated to enable us to compare all pairs. As in the previous analyses (Analyses 1), random effects were limited to by-subjects and by-items intercepts.

With the exception of the acoustic duration variable, which was significant at $p < .05$ in written naming, the patterns of reliable main effects in each spelling task were the same as those reported above. In written naming only, we observed reliable negative effects of name agreement, image agreement, and imageability. These effects were also reliably more negative than in the other two tasks. We found a reliable positive effect of frequency trajectory in written naming ($p < .01$) that was reliably different from that observed in both spelling to dictation and copying. The pattern of results concerning acoustic duration was somewhat more complex. It was reliable and positive in spelling to dictation but, as already mentioned, it was also surprisingly reliable in written naming (at $p < .05$). Moreover, there were significant differences between the three spelling tasks on this variable.

Turning now to “less task-dependent” variables (see Figure 2), the effect of word frequency was stronger in written naming than in both spelling to dictation and copying. The effect of word

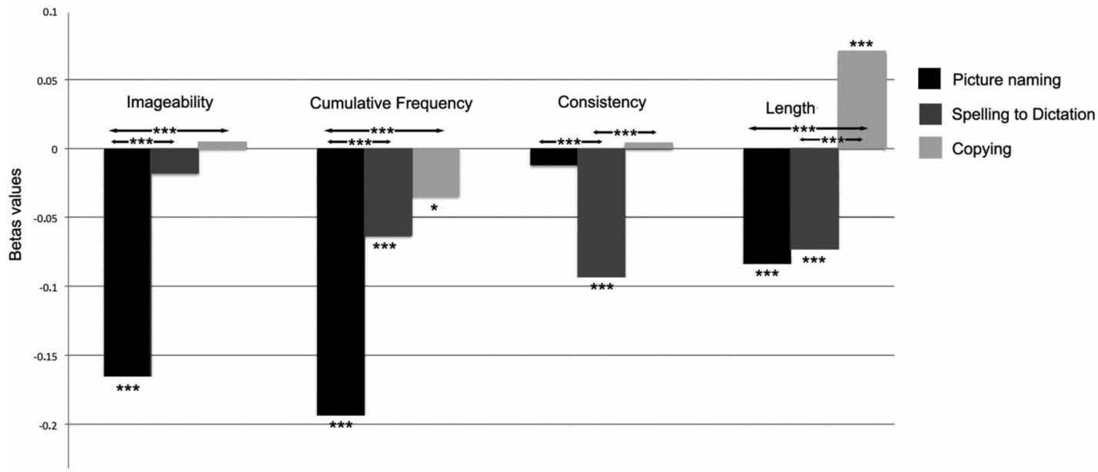

Figure 2. *Betas values for independent variables common to the three spelling tasks.* *** *= significant within-task effect at* p < *.001;* * *= significant within-task effect at* p < *.05; arrows are used to indicate reliable between-task differences at* p < *.001.*

frequency was nearly the same in spelling to dictation and copying. The effect of PO consistency was reliable only in spelling to dictation. In this latter task, the effect of the number of letters was reliably negative. It was similar to that found in written naming. Importantly, in the copying task, the effect of the number of letters factor was reliable but opposite in direction to that found in the other two spelling tasks.

In order to study whether, given the exclusion rules that we used, some of the observed effects might have been relatively dependent on long latencies and/or the definition of thresholds, the results were compared with those obtained using both a more stringent exclusion procedure and an observer's independent approach (the Tukey approach, Tukey, 1977). As far as the first procedure is concerned, after excluding all trials more than 2.5 standard deviations above or below either the participant or item means, we found the same patterns of fixed effects in both analyses. The only difference worth mentioning is that an unstable effect of bigram frequency was observed. For instance, there were significant facilitatory effects at $p < .05$ in spelling to dictation and copying in within-task linear mixed models without random slopes. However, the effect reached significance in spelling to dictation and was reliably "inhibitory" in written naming in the between-tasks linear mixed model analyses without random slopes. Importantly and succinctly, the use of a more stringent exclusion procedure does not change the theoretical implications of our findings (see General Discussion). Turning to the use of the Tukey approach, which consists in excluding, for each participant, response latencies lower (higher) than three times the Q3–Q1 distance below Q1 (above Q3), this provided exactly the same results as those obtained using the threshold plus 3 standard deviations criteria, except that the difference between written naming and copying was found to be not reliable for acoustic duration.

Analyses 3: Individual differences

We designed a second series of within-tasks linear mixed model analyses in order to investigate individual differences. By-participants random slopes for certain independent variables (see below) were included in order to estimate by-participants adjustments of the corresponding effects. For each participant, this made it possible to obtain an individual estimation of the effect of a given independent variable (given by the sum of the fixed effect and its adjustment). For example, if a participant was particularly sensitive to the facilitatory effect of word frequency, then the adjustment of this effect relative to the fixed effect of this variable should be among the most negative by-participants adjustments, and, as a result, the effect of word frequency on the associated RTs should also be among the most negative. The use of such adjustments is therefore similar to that of random regression (Lorch & Myers, 1990), except that both fixed and by-participants effects are estimated during the same procedure, thus avoiding, in particular, poor estimations of residual variance (e.g., Baayen, 2008). By-participants effects can then be used for two different purposes. The first is to investigate the extent to which the by-participants effects of an independent variable are related to the (by-participants) effects of other independent variables (see Table 6). The second is to study the extent to which the by-participants effects of an independent variable are associated with certain other characteristics of the subjects (e.g., their mean RTs in Table 7 or a vocabulary test in Bonin, Méot, et al., 2013, study, which involved the use of random regression).

Fixed effects were included for the same independent variables as those in the previous analyses—namely, imageability, cumulative frequency, frequency trajectory, number of letters, PO consistency, name and image agreement, and acoustic duration. It was not possible to include participants' random slopes for all independent variables because of the absence of convergence.

Therefore, the following inclusion rules were used. First, random effects were included for all independent variables that showed reliable fixed effects in both Analyses 1 and Analyses 2. Second, a stepwise procedure was used to examine participants' random slopes on nonincluded independent variables; and, third, individual tests were run for all the independent variables entered in the equations (forced + stepwise entered independent variables). Log-likelihood ratio tests were used for the random slopes of the individual independent variables (IVs) in the equation.

In written naming, the fixed effects that were reliable were the same and of the same signs as those observed when the random effects of IVs were not included. Moreover, independent variables without reliable fixed effects in both Analyses 1 and Analyses 2 did not show reliable fixed or random effects in the current analysis. Four independent variables exhibited both reliable fixed and random effects—namely, name agreement, $\chi^2(7) = 23.18$, $p < .01$, imageability, $\chi^2(7) = 23.94$, $p < .01$, cumulative frequency, $\chi^2(7) = 27.97$, $p < .001$, and frequency trajectory, $\chi^2(7) = 15.97$, $p < .05$.

In spelling to dictation, the significant fixed effects were the same (and of the same signs) as those previously found when the random effects of independent variables were not included. Moreover, as found in Analyses 2, the effect of number of letters was reliable, $t(257.28) = -3.23$, $p < .01$. Three independent variables had reliable random effects—namely, acoustic duration, $\chi^2(5) = 32.9$, $p < .001$, number of letters, $\chi^2(5) = 17.25$, $p < .01$, and PO consistency, $\chi^2(5) = 14.2$, $p < .05$. Finally, in the copying task, only the number of letters factor exhibited reliable random effects, $\chi^2(4) = 28.4$, $p < .001$. The fixed reliable effects were the same as those found in the analysis without random slopes.[3]

Estimations of the individual effects were obtained using the ranef function available in the lme4 package of R (Bates & Sarkar, 2007; Bates, Maechler, Bolker, & Walker, 2014).[4] As explained at the beginning of the subsection "Analyses 3", these adjustments reveal differential sensitivities of the participants to the independent variables. They can be used both to study the interrelations between these effects and to explore their links with other characteristics of the participants.

The relationships between reliable random effects obtained in the three different tasks were

[3]These were: name agreement, image agreement, imageability, number of letters, cumulative frequency, and frequency trajectory in written naming; acoustic duration, initial PO consistency, and cumulative frequency in spelling to dictation; and number of letters and cumulative frequency in copying.

[4]Only independent variables for which there were significant random effects were kept in the models.

Table 6. *Bivariate correlations between reliable random effects*

	Naming				*Spelling to dictation*				*Copying*	
	Imageability	*Cumulative frequency*	*Frequency trajectory*	*Name agreement*	*Intercept*	*Consistency*	*Length*	*Acoustic duration*	*Intercept*	*Length*
Written naming										
Intercept	−.686***	.275	−.076	−.250	.545***	.151	−.392*	.337	.691***	.428*
Imageability		.353*	.222		−.236	.154	.158	−.210	−.206	−.265
Cumulative frequency			−.330		.269	.432*	−.268	.134	.479**	.071
Frequency trajectory					.031	−.068	.069	−.073	−.033	.070
Name agreement	.088	.368*	−.841****		−.140	−.027	.047	−.019	−.189	−.333
Spelling to dictation										
Intercept						.287	−.906***	.860***	.411*	.122
Initial consistency									.399*	.332
Length						−.440*			−.223	−.055
Acoustic durations						.150	−.950***		.055	−.076
Copying										
Intercept										.690***

*$p < .05$. **$p < .01$. ***$p < .001$.

Table 7. *Results of the within-task regression analyses between participants' RT means and estimated random adjustments of the slopes*

	Written naming $R^2 = .94$		*Spelling to dictation* $R^2 = .77$		*Copying* $R^2 = .47$	
	b	t	b	t	b	t
Imageability	−0.904	−14.26***				
Cumulative frequency	0.781	13.74***				
Frequency trajectory	0.011	0.10				
Initial consistency			0.16	1.81†		
Length			*−0.97****	*−11.53****	0.688	5.19***
Name agreement	−0.443	−4.31***				
Acoustic duration (ms)			0.84	9.18***		

Note: RT = reaction time. In spelling to dictation, the results are for an equation including acoustic durations, and initial phonology-to-orthography (PO) consistency. Subjects' adjustments are reported in roman; italics are used for reporting the test of orthographic length. Subjects' adjustments in the equation do not include acoustic durations. The pattern of cumulative frequency and initial PO consistency effects was the same in the two equations.
$^{***}p < .001$. $^{\dagger}p < .1$.

first investigated by means of bivariate correlations between the estimated corresponding by-subjects adjustments.

The first aspect worth mentioning is that the random intercepts were positively correlated, which suggests that the slowest participants were generally the same across the three tasks. Concerning the relationships in written naming, we found the following. First of all, intercept adjustments were negatively correlated with imageability subjects' random effects, thus suggesting that the slowest participants were also generally more sensitive to this dimension. Thus, imageability was more facilitatory among the slowest participants. Second, the subjects' random name agreement and frequency trajectory effects were negatively and highly correlated, thus suggesting that the participants who benefited the most from name agreement (higher negative corrections compared to the fixed effect of name agreement) were also more affected by low-frequency trajectory (higher positive corrections). One less obvious aspect of the data concerns the positive correlations found between name agreement (or imageability) and word frequency, which suggests that the participants who benefited the most from name agreement or imageability also benefited more from higher cumulative frequency.

Turning to spelling to dictation, the intercept adjustments were, unsurprisingly, very positively correlated with those of the acoustic duration slope: The slowest participants were generally the most affected by acoustic duration. The same kind of relationship as that found between the fixed effects of acoustic duration and orthographic length was also observed at subject level: The more negative the influence of acoustic duration was, the higher the facilitatory effect of orthographic length. Finally, as far as the copying task is concerned, the slower participants were also the most sensitive to the negative effect of the number of letters.

To gain a better understanding of the relationships between the variables described above, within-task regression analyses were computed between participants' mean RTs as a dependent variable and estimated reliable random adjustments of the slopes as independent variables. (It is important to note here that the former were nearly perfectly correlated with the subjects' adjustments of the intercepts.) Given the very high redundancy between the acoustic duration and orthographic length effects observed in the participants, only acoustic duration was included in the equation for spelling to dictation. As can be seen from Table 7, except for the copying task, participants' mean RTs were very highly predicted by the adjustments of the slopes.

In written naming, the slowest participants were more sensitive to the facilitatory effects of name agreement and imageability, whereas the opposite was observed as far as the effect of word frequency is concerned. Figure 3 illustrates the relationship between the by-participants effect of imageability (on the *x*-axis) and mean written naming latencies (on the *y*-axis). (This figure is provided by way of an example in order to aid in the understanding of the correlational analyses.) As can be seen from Figure 3, the by-participants imageability effects were all negative, thus indicating that imageability has a facilitatory effect on the time taken to initiate writing. The figure also shows that the greater the facilitatory effect of imageability was, the higher the participants means were—that is to say that it was greater with slower participants.

In spelling to dictation, the slowest participants were more sensitive to the inhibitory effect of acoustic duration (it is worth noting that when number of letters was used instead of acoustic duration, these participants were also more sensitive to the facilitatory effect of this variable). The positive coefficient of initial PO consistency, even though it was only marginally significant, suggests that the slower the participants were, the less sensitive they were to the facilitatory effect of this variable. Not surprisingly, in the copying task, the slowest participants were more affected by the number of letters.

Although generally less strong, certain between-tasks correlations between subjects' adjustments were also reliable (see Table 6). This observation is consistent with the previous findings. We found the following pattern of results. First of all, the random effects of naming intercepts revealed the same kind of relations with orthographic spelling length adjustments as the random intercepts for spelling. This indicates that the slowest participants in written naming tended to benefit more from number of letters in spelling to dictation. Second, and unsurprisingly, these participants also tended to be more affected by the number of letters in the copying task. Third, cumulative

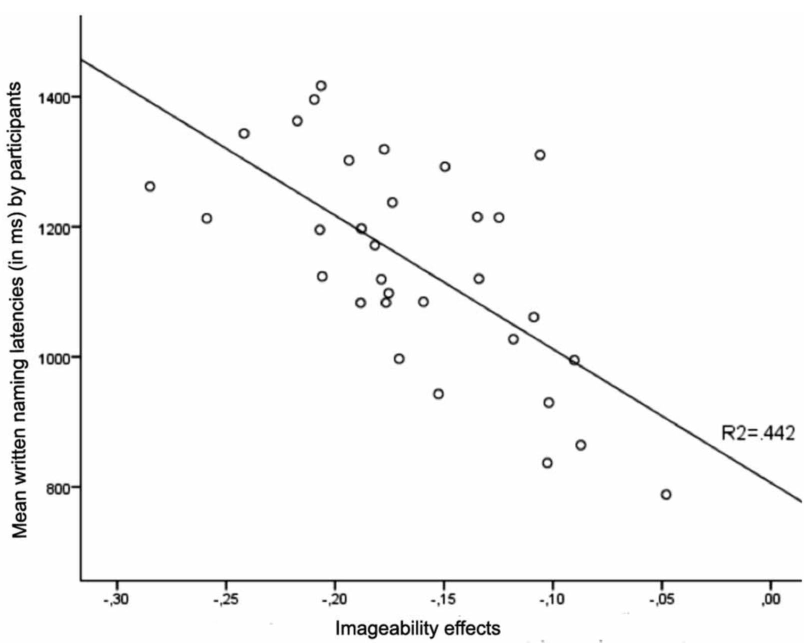

Figure 3. *Distribution of mean written latencies by participants as a function of their imageability effects (fixed effect + by-participants adjustments) in written naming.*

frequency adjustments in naming were positively correlated with the random effects of consistency in spelling—that is to say, the more the participants benefited from word frequency in written naming, the more they benefited from consistency in spelling. Fourth, word frequency adjustments in naming were also positively correlated with intercept adjustments in copying: The less sensitive the participants were to word frequency in written naming, the slower they were in the copying task. Fifth, the slowest participants in the copying task were also less sensitive to the facilitatory effect of PO consistency in spelling.

Analyses 4: Error analyses

The different types of errors are reported in Table 2 and have already been described earlier. Given the low number of phonologically plausible errors or orthographic-only errors, we did not model these based on the characteristics of the items or of the participants. Bivariate correlations were used instead. As there were only 17 phonologically plausible errors in the copying task, we did not take them into account in these analyses.

At the item level, the correlations between the different kinds of errors were all positive—but only partly reliable. The highest was observed between phonologically plausible errors obtained in written naming and spelling to dictation ($r = .798$, $p < .001$). Orthographic errors obtained in the different tasks were also all relatively highly correlated (the correlations varied between .446 and .494, all $p < .001$). A reliable within-task relation between phonologically plausible errors (PPE) and orthographic errors (OE) was observed only for spelling ($r = .256$, $p < .001$), while a noticeable correlation appeared between phonologically plausible errors in written naming and orthographic-only errors in spelling ($r = .314$, $p < .001$). Finally, phonologically plausible errors in both written naming and spelling to dictation were both weakly correlated with orthographic-only errors in copying ($r = .151$, $p < .05$, and $r = .175$, $p < .01$).

No apparent relations were observed between errors of any kind in any tasks and mean item latencies in written naming. By contrast, all correlations with the latencies obtained in the other two tasks were positive—but low (between .073 and .217).

Finally, and still at the item level, all errors were positively and reliably correlated with the number of letters (r between .145 and .304). They were also all negatively associated with cumulative frequency (r between −.103 and −.246), and all reached significance except for orthographic-only errors in written naming. More surprisingly, except for phonologically plausible errors in spelling, which were not reliable, all errors were also positively correlated with acoustic duration (r between .131 and .233).

At the participant level, the correlations between the numbers of errors and mean RTs were also low and not reliable, except for the correlation between phonologically plausible errors in spelling to dictation and mean RT in written naming ($r = .399$, $p < .05$). With the exception of phonologically plausible errors and orthographic errors in spelling to dictation, which did not reach significance, all other errors were positively and reliably correlated (r from .42 to .75).

All types of errors exhibited very few reliable relationships with the subjects' adjustments of the intercepts or slopes obtained in the last mixed models computed on trial RTs. Only phonologically plausible errors in spelling showed reliable relationships with the intercept and imageability slope adjustments in written naming: Higher numbers of phonologically plausible errors in spelling to dictation were associated with longer times in written naming and a greater sensitivity to the facilitatory effect of imageability. It is, however, interesting to note that, although not reliable, the other correlations with imageability adjustments were all negative (between −.153 and −.344), thus suggesting that the participants who were more sensitive to imageability generally produced more errors of all kinds in all the tasks.

Discussion

According to most theoretical views of word spelling (e.g., Bonin et al., 2012; Kandel et al., 2011; Miceli, 2001; Rapp et al., 2002; Tainturier &

Rapp, 2001), two pathways—lexical and nonlexical—are available to write down the orthography of words from different kinds of input: visual input (pictures of objects); auditory or visual input (words heard or seen). As illustrated in Figure 1 and reviewed in the Introduction, the nonlexical pathway involves the operation of sublexical conversion procedures, while the lexical pathway requires the retrieval of orthographic codes from the orthographic lexicon. However, these views are underspecified at the level of the functional involvement of the two pathways depending on the spelling task: written naming, spelling to dictation, or copying. In other words, the respective roles of the lexical and nonlexical pathways have not always been clearly distinguished between in terms of their contribution to the production of word spellings. The primary goal of the present study was therefore to investigate the involvement of the lexical and nonlexical pathways in the real-time handwriting of words as a function of these three spelling tasks. To index the involvement of the two pathways, we observed the effects of two variables that have been assumed to reveal their mobilization. Word frequency was used as an index of the mobilization of the lexical pathway, and phonology-to-orthography consistency was used to signal the involvement of the nonlexical pathway. A more secondary goal was to investigate individual differences in word spelling. In our study, participants had to write down the same set of words in three different spelling tasks performed on three different occasions. It was therefore possible to make cross-task as well as within- and between-individual comparisons. To our knowledge, our study is the first to have investigated the same spelling tasks across the same participants using the same items. As we discuss below, the findings on the written latencies resulting from cross-task comparisons have important theoretical implications. In effect, they suggest that the lexical pathway is involved in all spelling tasks (although it makes a stronger contribution in written naming than in spelling to dictation or copying) because, as we explain above, the influence of word frequency is considered to be a genuine index of the involvement of the lexical pathway. In contrast, the nonlexical pathway is reliably dominant in spelling to dictation only if we assume that the phonology-to-orthography consistency variable reliably indexes mobilization of the nonlexical pathway. Our findings also show that depending on their general speed of writing preparation and the types of spelling tasks, individuals do not rely to the same extent on the same type of information to perform word spelling.

Cross-task comparisons

Three important findings on the speed of preparation of handwriting responses emerge from the cross-task comparisons. The first aspect to discuss is word frequency. Word frequency is assumed to index the contribution of the lexical route (Bonin, Méot, et al. 2013; Bonin et al., 2012). First of all, the effect of word frequency on the time taken to initiate a handwriting response was stronger in written naming than in either spelling to dictation or copying. Indeed, the impact of word frequency was nearly the same in both spelling to dictation and in copying. As reviewed in the Introduction, the finding of word frequency effects in written naming and spelling-to-dictation latencies has already been reported in previous studies (Bonin et al., 2012; Delattre et al., 2006) and does not constitute in itself a novel feature of the present study. Nevertheless, it should be noted that, as far as copying is concerned, word frequency effects in written latencies have not often been reported. In Bonin, Fayol, and Gombert (1998), a word frequency effect was found in copying but the word frequency measures used were outdated. Using more up-to-date word frequency measures than those used by Bonin, Fayol and Gombert (1998), Lambert et al. (2011) found an effect of word frequency on latencies in immediate copying, and even more recently, Roux et al. (2013) reported a lexicality effect on latencies, which can be thought of as an extreme case of frequency effects (where words = familiar items, and pseudowords = unfamiliar, since unknown, items). In line with these findings, we also found that word frequency had a reliable influence on copying latencies in our study.

The extent to which word frequency is involved in these spelling tasks was one important issue of our study that had not previously been explored in depth. Our findings indicate a stronger contribution of word frequency when participants produce the spelling of words in written naming than in either spelling or copying. But why is the weight of word frequency stronger in written naming than in spelling to dictation or copying? One implication of the observation of a difference between the impact of word frequency in written naming and in the other two tasks is that these effects can certainly not be ascribed to a single processing level shared across tasks—namely, the output lexical orthographic level. An implicit assumption in the adult word spelling literature has been that word frequency effects are located at the level of orthographic word-form representations (Shi Min & Liow, in press). Following various proposals made in the field of spoken word production (e.g., Caramazza, 1997; Dell, 1990; Levelt, Roelofs, & Meyer, 1999), it might be possible that word frequency is implemented in the resting activation levels of orthographic word-form representations in a localist spreading-activation network (e.g., Dell, 1990, for such a view in spoken word production). Alternatively, word frequency could also be implemented either as the word form's activation threshold—that is, low for high-frequency words and high for low-frequency words—as suggested by Jescheniak and Levelt (1994), or as described in the WEAVER++ model of spoken word production (Roelofs, 1997, 2000), in which the influence of word frequency in written naming is thought to be due to differences in the time taken to verify the links between the lemma (the lexicosyntaxic) and the orthographic word-form levels, with those corresponding to high-frequency items taking less time to verify than those associated with low-frequency items. As reviewed by Knobel, Finkbeiner, and Caramazza (2008), word frequency effects in word production could also arise at the interface between semantics and the lexicon and/or at the interface between the lexicon and phonology.

However, it is important to stress that *within a single task* (e.g., written naming or spelling to dictation), different hypotheses have been put forward in the literature about the locus/i of word frequency effects. For instance, in conceptually driven naming, Knobel et al. (2008) have identified five potential loci for word frequency effects in word production. However, in a recent study of written object naming, Bonin et al. (2012) claimed that "word frequency effects may be interpreted as a genuine signature of the ease of processing at the orthographic word-form level in written naming in much the same way that frequency affects the phonological level in spoken word production (Mädebach, Jescheniak, Oppermann, & Schriefers, 2011)" (pp. 1752–1753). Thus, Bonin et al. (2012) located word frequency effects in written naming at one level only: the orthographic output lexicon.

The observation that word frequency effects on the time taken to initiate a handwriting response are nearly the same in spelling to dictation and in copying could be taken as an indication that these effects act at a locus common to both tasks. One potential candidate could be the orthographic word-form level, which has also been considered in connection with written naming (Bonin et al., 2012). However, according to Shi Min and Liow (in press), and in line with the Tainturier and Rapp (2001) model of spelling to dictation, there are two other possible loci for word frequency effects apart from the orthographic word-form level: spoken word recognition and response execution of the first letter. On the basis of the results obtained from two experiments, Shi Min and Liow (in press) have claimed that frequency effects in spoken word recognition play a substantial role in skilled spelling to dictation.

Since the aim of our study was not to identify the precise locus/i of word frequency effects on the speed of preparation of handwriting responses in written naming, spelling to dictation, or copying, further work will be required to distinguish between the different hypotheses that may account for word frequency effects in these tasks. Clearly, there is scope for future research work on this topic. However, we think that our study makes it clear that word frequency effects on writing latencies in written naming do not translate directly to those found in spelling to dictation or in copying, and that there is certainly no single locus of word frequency effects common to written naming, spelling to dictation, and copying. From a methodological point of view, since the three spelling tasks make it possible to detect word frequency effects on writing latencies, all of them can be used if the research aim is to investigate these effects.

If we now turn to the influence of PO consistency, this had a reliable influence only in spelling-to-dictation latencies. The PO consistency variable has been assumed to be a genuine index of the involvement of the nonlexical pathway (Bonin, Méot et al., 2013; Tainturier & Rapp, 2001). PO consistency effects have often been reported in spelling-to-dictation tasks in healthy adults (e.g., Bonin et al., 2005; Bonin & Méot, 2002; Bonin, Peereman et al., 2001; Delattre et al., 2006). In the same way as in our copying task, neither Lambert et al. (2011) nor Roux et al. (2013) found a reliable effect of consistency on word writing latencies.

As far as written naming is concerned, the effect of this variable was initially reported by Bonin, Peereman et al. (2001). To our knowledge, however, the Bonin, Peereman et al. (2001) study is the only one to have reported initial consistency effects in written naming latencies. Based on this finding, Bonin, Peereman et al. (2001) have claimed that written naming is constrained by phonological codes. It should be noted, however, that the findings of more recent studies that have investigated the influence of phonology in written word production have been rather inconsistent. As reviewed in the introduction, certain studies have reported evidence that phonology is involved in written word production (e.g., Damian et al., 2011; Damian & Qu, 2013; Qu et al., 2011; Zhang & Damian, 2010). However, it is important to stress that picture–word interference studies have shown that phonology is activated *only* at an early stage during the course of writing. At the same time, certain studies have failed to find a reliable contribution of phonology in written word production (Bonin, Fayol, & Peereman, 1998; Roux & Bonin, 2012). Therefore, while we do not deny that phonology may play a role in orthographic encoding in written naming under certain conditions, the contribution of phonology is not a strong one. Of course, this latter interpretation is built on the assumption that initial consistency is a measure that reliably captures sublexical phonological effects and, thus, the influence of phonology. However, reliable effects of PO consistency have been found in written naming latencies only when initial consistency has been measures. When final (or middle) consistency measures have been used, no reliable effects of consistency in written naming have been observed (Bonin, Peereman et al., 2001). Importantly, in the Bonin, Peereman et al. (2001) study, this was not due to the lack of sensitivity of the middle/final PO consistency measures used given that there were strong effects of middle/final PO consistency in spelling to dictation.

The observation that the nonlexical pathway is reliably involved only in spelling to dictation, and thus not reliably so in either written naming or copying, suggests that most theoretical views of written naming and copying have certainly placed too much emphasis on its potential contribution in healthy adults. For instance, in the working model depicted in Figure 1, which was framed on the basis of previous theoretical proposals (e.g., Bonin et al., 2012; Cuetos, 1991; Rapp et al., 2002; Tainturier & Rapp, 2001), a nonlexical pathway is available to perform each type of spelling task. Of course, we are not suggesting that a nonlexical pathway is never involved when spelling words from either their visual or their pictorial presentation. However, our findings strongly suggest that when healthy adults produce familiar words, this pathway, though potentially available, as suggested for instance by analyses of brain-damaged patients (Tainturier & Rapp, 2001), does not play a crucial role. In other words, the nonlexical route is certainly entrenched in the cognitive architecture of written naming and copying, with the result that it can be used under some specific occasions (e.g., in cases of brain damage; for unknown words), even though its functional role tends to be rather limited when producing individual familiar words. One methodological implication of this pattern of findings is that researchers who wish to investigate consistency effects in handwriting should choose spelling to dictation rather than written naming or copying since these effects show up more easily in the former than in the latter two tasks.

Although length effects were not the focus of our study, we also found differential effects of number of letters in written naming, spelling to dictation, and copying. The effect of number of letters on latencies was reliably negative in written naming (in the Bonin et al., 2004, study, this factor did not reach significance), negative (but marginally so in Analyses 1 and reliable in Analyses 3 and 4) in spelling to dictation, and positive in copying. In copying, orthographic information is available as on the presentation of the word, and the effect of the number of letters could therefore be due to the fact that longer words take longer to visually encode than shorter words (i.e., there are more saccades and/or more longer fixations). As far as spelling to dictation is concerned, we found that the effect of length was negative, with the result that words with more letters were produced faster than those with fewer letters. Although at first glance, this result is somewhat counterintuitive, it had already been reported in the Bonin et al. (2004) study, as well as in a more recent study (Bonin, Méot et al., 2013). In Bonin, Méot et al. (2013), we explained it as a suppression effect associated with the acoustic duration effect—that is to say that when acoustic durations were similar, words were completed more quickly when they contained more letters. It is clear that word length effects in lexical processing tasks have not been proved easy to account for. For instance, in visual word recognition, the influence of the number of letters has also been found to have a nontrivial (and somewhat complex) relationship with lexical decision times (see Ferrand et al., 2010). In spoken naming, an effect of word length has been found in some studies (e.g., Meyer, Roelofs, & Levelt, 2003) but not in others (e.g., Damian, Bowers, Stadthagen-Gonzalez, & Spalek, 2010).

Finally, there are two other findings that deserve some discussion: imageability and frequency trajectory effects.

Imageability is assumed to index semantic code activation (Evans, Lambon Ralph, & Woollams, 2012). This variable has recently been reported to be a strong determinant of spoken naming latencies (Bonin, Guillemard-Tsaparina, & Méot, 2013), which is unsurprising given that spoken naming is obviously a semantically mediated task (Bonin et al., 2012). In effect, most theories of object naming assume that access to the word form of the name of a presented object necessarily requires semantic mediation (Bonin et al., 2012). Indeed, we know of no unambiguous cases of patients who can name objects that they are unable to comprehend. Given that it has been assumed that spoken and written naming share the semantic level (Bonin & Fayol, 2000; Perret & Laganaro, 2012), we very much expected to find an effect of imageability in written naming, and this expectation was borne out by our results (Analyses 1).

It has been assumed that spelling to dictation and copying are less dependent on semantic codes. Therefore, as revealed by the cross-task comparisons, the observation that imageability plays a greater role in written naming than in spelling to dictation and copying is not surprising. As shown in Figure 1, spelling to dictation and copying are able to "catch" sublexical processes earlier than in written naming, and it is therefore possible to connect orthographic codes without the involvement of semantic codes. In written naming, there is no sublexical route from the input identification processes (see Figure 1) that connects directly with orthographic codes. A sublexical route is involved only when phonological codes have been retrieved from semantics (Figure 1).

Our findings in spelling to dictation are in line with those of a recent study of spelling to dictation (Bonin, Méot et al., 2013) that did not find that imageability made a reliable independent contribution to spelling latencies. However, the absence of reliable effects of imageability in spelling-to-dictation or copying latencies should not be interpreted as suggesting that semantic codes do not play a role when spelling words to dictation or when copying them. Instead, it merely suggests that there is a differential involvement of semantic codes in these three tasks.

In line with previous findings (Bonin et al., 2004), we found a reliable positive effect of frequency trajectory in written naming. However, this effect was reliable neither in spelling to dictation nor in copying. In the Bonin et al. (2004) study, there was also no reliable effect of frequency trajectory on spelling-to-dictation latencies. This type of result was predicted, since frequency trajectory effects are generally found in tasks that involve arbitrary mappings, such as object naming or face naming, and not in tasks such as spelling to dictation or copying, which involve quasiregular mappings in both French and English (see Lété & Bonin, 2013; Mermillod, Bonin, Méot, Ferrand, & Paindavoine, 2012, for further evidence and full discussion).

Turning to task-specific effects, these were consistent with previous studies and thus are not discussed in full. Likewise, in written naming, we found that name agreement and image agreement were reliable determinants of written latencies. These factors are often reported as strong determinants of naming speed (e.g., Alario et al., 2004; Bonin et al., 2002). In spelling to dictation, we found that acoustic duration was a strong determinant of spelling latencies as reported by both Bonin and Méot (2002) and Bonin, Méot et al. (2013). Words having long acoustic durations took longer to initiate than words having shorter acoustic durations. Since the processing of the auditory string is necessarily distributed over time, words that take more time to be heard take longer to process than those that take less time to be fully heard. This delay is reflected in the latencies. It might be thought that acoustic duration provides a fairly straightforward measurement of phonology in phonological working memory.[5] Acoustic duration in the between-task comparisons was found to be reliably stronger in spelling to dictation than in both written naming and copying (it is worth recalling here that when the Tukey procedure was applied, the difference between written naming and copying was not significant). However, given that the effect of acoustic duration on the latencies was not really strong in written naming and, furthermore, that it was not reliable in copying, the suggestion that acoustic duration is a reflection of phonology in phonological working memory will need to be substantiated by further evidence. Finally, concerning the effect of the number of letters, it is possible to conjecture that participants delay their spelling output until they estimate it to be reliable. However, for similar acoustic durations, the spelling output is made available earlier for long than for short words.

Individual differences in the speed of preparation of handwriting responses

The analyses of individual comparisons revealed some interesting findings. The first aspect of note is that participants who were slow in one task were generally slow in the other two tasks.

In written naming, we found that the imageability values of the words helped the slowest participants the most (Figure 3). Since imageability is assumed to index semantic code activation (Evans et al., 2012), this suggests that the slowest participants needed to rely more on semantic information than did the faster participants. The slowest participants were also helped more by high name agreement values. Since name agreement has often been considered to index the link between semantic and lexical codes, this again suggests that the slowest participants were more dependent on semantic information. However, and again at the level of written naming, the slower participants were helped the least by higher word frequency values, again suggesting that these participants were more reliant on semantic than on lexical information. In spelling to dictation, the slowest participants were more impeded by the harmful effect of acoustic duration. Not surprisingly, in the copying task, the slowest participants were hindered more by longer than by shorter words in terms of the time taken to initiate responses. We assume that the length effect in copying takes place at the level of orthographic working memory. In order

[5]We thank an anonymous reviewer for pointing this out to us.

to produce a word from its visual presentation, it is necessary to gaze at it and memorize it before positioning the stylus over the tablet, since at the time the stylus makes contact with the tablet it is no longer available for visual inspection. Longer words take more time to gaze at and refresh. Slower participants may compensate for their slowness by spending more time looking at the longer words. In effect, since they are slow to initiate writing, then, in the case of longer words, they run the risk of having forgotten some of the information extracted from the visual presentation of the words unless they spend longer processing them.

Finally, before concluding, the main findings on errors were as follows. At participant and item levels, all errors were generally positively (and reliably) correlated, thus indicating that the participants and items associated with high rates of errors were the same in all tasks. On the items only, and in all three tasks, positive relations (not all reliable) were also observed between all types of errors and the latencies in spelling and copying. Again, at item level only, there were more errors on longer words and fewer errors on high-frequency words. One surprising observation was that in every task, there were more errors on words having longer acoustic durations. Thus, this observation suggests that these errors have a similar origin. There were very few relations worthy of note at participant level, with the exception of imageability, which had a systematic effect on the number of errors, with the result that individuals who were the most sensitive to this variable tended to produce more errors.

To conclude, our study makes a valuable contribution by suggesting that different spelling tasks involve different processing pathways. More precisely, although written naming, spelling to dictation, and copying all rely on a lexical pathway, written naming is more dependent on the lexical pathway than is spelling or copying. Furthermore, only spelling to dictation significantly mobilizes a nonlexical pathway. Finally, the analyses performed at the level of participants revealed that the slower participants were more or less influenced by certain variables depending on the type of task used for spelling.

Supplemental material

Supplemental material (data together with some of the associated analysis scripts) is available on the Internet at the following URL: http://leadserv.u-bourgogne.fr/webpagepabonin

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