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Chapter 8

WRITING TO DICTATION IN REAL TIME IN ADULTS: WHAT ARE THE DETERMINANTS OF WRITTEN LATENCIES?

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ABSTRACT

The influence of seven variables on the latencies for writing down 164 nouns was investigated in written spelling to dictation in adults. Multiple regression analyses revealed that the variables which made an independent significant contribution to the spelling latencies were: acoustic duration of the items, age-of-acquisition (AoA), word frequency, phonology-to-orthography (PO) consistency and orthographic length (number of letters). Also, two three-way interactions were found: imageability x AoA x PO consistency and imageability x word frequency x PO consistency. The findings suggest that both lexical and sublexical knowledge contribute to adults' performance in the real-time written spelling to dictation of words and that the effect of semantic activation emerges when the computation of orthographic codes from phonological codes is slow as is the case for inconsistent low-frequency/late acquired words. The findings are discussed in relation to the dual-route view of spelling to dictation and to connectionist networks.

Key Words: word frequency, age-of-acquisition, imageability, phonology-to-orthography consistency, writing to dictation

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In psycholinguistics, research on reading is far more advanced than research on spelling. Our knowledge about the spelling process in adults is largely based on studies of brain-damaged patients. Thus far, there have been a limited number of investigations of spelling in adults using real-time paradigms (Bonin, Peereman, & Fayol, 2001; Glover & Brown, 1994; Kreiner, 1992, 1996). In the present study, we investigated writing to dication in adults using an on-line paradigm that permits the recording of the written latencies. The goal was to identify some of the major determinants of onset latencies in writing to dictation in adults using a large set of items and multiple regression analyses in order to constrain the modeling of spelling to dictation in normals.

Surprisingly, only a few studies of spelling to dictation in normals have attempted to delineate the factors that may be critical to spelling performance by means of regression analyses (e.g., Kreiner, 1992; Kreiner & Gough, 1990). This situation stands in sharp contrast to picture naming studies which have made widespread use of this methodology (e.g., Barry, Morrison, & Ellis, 1997; Bonin, Chalard, Méot, & Fayol, 2002; Cycowicz, Friedman, Rothstein, & Snodgrass, 1997; Ellis & Morrison, 1998; Morrison, Ellis, & Quinlan, 1992; Snodgrass & Yuditsky, 1996). Studies of this kind are important from an empirical point of view, because they have made it possible to highlight the critical variables that have to be taken into account in future research on writing to dictation. Also, from a theoretical point of view, they may provide additional constraints that are useful in the modeling of the spelling/writing process in adults.

As regards spelling/writing to dictation, the most commonly held view is the dual-route view (e.g., Ellis, 1982, 1984, 1988; Hatfield & Patterson, 1984; Kreiner, 1992; Kreiner & Gough, 1990; Margolin, 1984; Rapp, Epstein, & Tainturier, 2002). Some connectionist alternatives exist (e.g., Brown & Loosemore, 1994; Houghton, Glasspool, & Shallice, 1994), but the literature has tended to focus on the dual-route view. Perhaps as a result, connectionist models of spelling are far from fully developped.

According to the dual-route view, skilled spellers have at their disposal two major processes or "routes" for translating phonology to orthography: the "lexical" route and the "nonlexical" (or sublexical) route. The lexical route delivers the spelling of known words by using lexical knowledge whereas the nonlexical route involves sound-to-spelling conversion processes that make use of some form of subword knowledge to build the spelling of words or nonwords.

The dual-route view of spelling is supported by various lines of argument but the most persuasive evidence in favor of this view has been provided by analyses of spelling errors produced by brain-damaged patients (Barry, 1994). Some patients with acquired dysgraphia have been shown to be able to spell nonwords while exhibiting poor performances when spelling irregular words (i.e., surface dysgraphia, see Baxter & Warrington, 1987; Beauvois & Dérouesné, 1981; Behrmann & Bub, 1992; Goodman & Caramazza, 1986; Goodman-Schulman & Caramazza 1987; Hatfield & Patterson, 1983; Sanders & Caramazza, 1990) whereas others have been reported to exhibit the opposite pattern of performance (i.e., phonological dysgraphia, see Baxter & Warrington, 1985; Bub & Kertesz, 1982; Goodman-Schulman & Caramazza, 1987; Shallice, 1981).

The Sublexical Route

The sublexical route operates through the application of knowledge of sound-to-spelling mappings. The phonological form of a spoken item is first segmented into smaller phonological units which are then converted into orthographic units. Theorists of spelling have been somewhat reticent concerning the precise characterization of the mode of operation of the phonology-to-orthography (PO) conversion procedure (Barry & Seymour, 1988). There are two issues that have been raised regarding the operation of the sublexical route: The nature of the subword parts on which the sublexical conversion procedure operates and the way phonology is mapped to orthography.

As regards the nature of the subword parts on which sublexical conversion is built, single phonemes were originally proposed but larger units have also been thought of as potential canditates, e.g., phoneme groups, syllables etc. (Baxter & Warrington, 1987; Tainturier, 1997). As far as the way the PO sublexical conversion procedure maps sound units to orthographic units is concerned, one issue has been the question of whether only one grapheme is represented as a mapping for each phoneme or whether there are representations of multiple spellings corresponding to each phoneme. Evidence stemming from the analyses of spelling errors produced by brain-damaged patients (e.g., Goodman & Caramazza, 1986; Sanders & Caramazza, 1990), but also from normals (Barry & Seymour, 1988), has revealed a huge variability in the spelling of the same phoneme sequences which strongly suggests that a single grapheme option is not encoded for each phoneme. These data are more compatible with the hypothesis that the sublexical conversion procedure encodes a range of the phoneme-to-grapheme options in the language. The selection among the possible mapping options for each phoneme would then be based on the frequency with which they occur within the language as evidenced by the strong correlation between the distribution of spellings produced for a given phoneme and the actual distribution of spellings in the language for that phoneme (Goodman & Caramazza, 1986; Sanders & Caramazza, 1990).

The Lexical Route or "Routes"

The lexical route is thought to retrieve the spelling of known words from an (output) orthographic lexicon. The retrieval of orthographic codes can be mediated by semantics or by (output) phonological representations or it can be "direct".[1] On this basis, different lexical processing pathways (or lexical routes) have been distinguished.

One route is a semantically-mediated route. A strong argument in favor of such a route has come from analyses of cases of deep dysgraphia (Bub & Kertesz, 1982). Deep dysgraphic patients are unable to spell nonwords but they can spell words, although they make semantic errors (e.g., *moon* → *sun*). Another lexical route makes use of output phonological representations to access orthographic representations (Ellis, 1982, 1988; Morton, 1980). Output phonological representations are contacted either from semantic representations or directly from input phonological representations in the auditory input lexicon. The empirical

[1] The existence of separate input and output phonological and orthographic lexicons, is assumed by some authors (Caramazza & Hillis, 1990; Morton & Patterson, 1980) but this assumption is controversial (Coltheart & Funnell, 1987; Holmes & Carruthers, 1998).

support for such a route comes from homophone substitution errors in writing, for instance producing the orthographic form "*buoy*" when "*boy*" is the intended one (Rapcsak & Rubens, 1990; Roetlgen, Rothi, & Heilman, 1986). Finally, a "direct" lexical route has also been put forward (Patterson, 1996): The input phonological representation from the input phonological lexicon directly activates its orthographic representation in the output orthographic lexicon. However, its existence has been disputed (see Hillis & Caramazza, 1991, 1995; Hillis, Rapp, Romani, & Caramazza, 1990).

Although the neuropsychological literature strongly suggests the existence of different processing pathways that are available in spelling/writing to dictation, the issue of the contribution of the different kinds of representations that are contacted during the normal real-time functioning of spelling remains unclear.

The Involvement of the Sublexical and Lexical Routes in Spelling to Dictation

Any dual-route model of spelling to dictation must account for the functional details of the real-time involvement of the two routes in normal spelling. According to one version of the dual-route view, the assembly route is "optionally" used to produce plausible spellings of nonwords, unknown words, incomplete or missing word spellings (Kreiner, 1992; Véronis, 1988). Hence, the primary procedure involved in normal spelling is the lexical route (Véronis, 1988). One argument for positing an optional role for the sublexical route comes from the fact that languages such as French or English are highly inconsistent as regards sound-to-spelling mappings. Consistency is generally defined as a measure of the degree to which a given sound unit (e.g., onset, rime, vowel, coda) is mapped to an orthographic unit (Peereman & Content, 1999). Estimations of the consistency of the mappings between sound and orthographic units in English and French (Ziegler, Jacobs, & Stone, 1996) have revealed that both languages are more consistent as regards the spelling-to-sound correspondences than the sound-to-spelling correspondences. By performing a computer simulation of a sound-to-spelling translation strategy that might be used by a native speaker of French, Véronis (1988) found that over half of the 3724 common French words processed by the algorithm contained a spelling peculiarity that could not be predicted from its sound (for similar results in English see Hanna, Hanna, Hodges, & Rudorf, 1966). From this simulation work, Véronis (1988) concluded that it was very unlikely that French spellers made use of an assembly route to write familiar words.

Another version of the dual-route view was put forward by Kreiner (1996). His parallel-interactive model of spelling fits in with the dual-route "horse race" models (see Paap & Noel, 1991; Paap, Noel, & Johansen, 1992, for a similar model in reading aloud). Horse race models claim that both routes are involved in parallel in the computation of a spelling pattern but differ in their general speed. The route that wins the race can trigger the spelling response. For high-frequency words, the lexical route usually provides the correct spelling before the nonlexical route has finished its computation, whereas in some trials both routes yield the same spelling at the same time. However, as the lexical route for low-frequency words is generally slower than for high-frequency words, competing responses can be delivered by the two routes when an "irregular/inconsistent" word has to be spelled. In such cases, the competition takes longer to resolve than when the two routes provide congruent spellings. Clearly, then, this version predicts that the regularity/consistency and word frequency variables interact (see Kreiner, 1996, for related evidence).

As proposed for reading aloud, the idea that the two routes in spelling are not independent, in the sense that they do share some processing levels, has been endorsed by Rapp et al. (2002). More precisely, Rapp et al. have proposed that the sublexical and lexical processes *integrate* information at a grapheme level. Such a view of spelling to dictation is supported by a wide range of empirical facts coming from brain-damage patients as well as from normals. For instance, the patient JJ (Hillis & Caramazza, 1991) made semantic errors in the spoken and written naming and comprehension of pictures but not in reading aloud or in spelling to dictation. The absence of semantic errors in oral reading and spelling to dictation has been attributed to the fact that information from lexical and sublexical processes combines to eliminate semantic errors. Rapp et al. have described the performance of a patient LAT which lends further clear support to the integration hypothesis. LAT produced many phonologically plausible responses in spelling to dictation on words which were better characterized as corresponding to the integrated output of graphemic elements generated by both the lexical and sublexical routes (e.g., *knolige* for *knowledge*).

The dual-route view of spelling to dictation provides a reasonable framework to account for observations essentially collected thus far from patients. However, a connectionnist approach such as the one advanced by Seidenberg and McClelland (1989) in word reading also has the potential to account for certain empirical facts in spelling/writing to dictation as we shall explain in the Discussion.

To summarize, evidence, drawn primarily from neuropsychological studies, favors the hypothesis that there are different kinds of processing pathways (or routes) that may be used in spelling to dictation. The translation of spelling from input phonology may therefore be achieved on the basis of different kinds of representations: semantic, lexical, sublexical. However, we are not aware of any recent study involving normal participants that has systematically investigated the contribution of these different kinds of knowledge in the real-time written spelling of words. As a result, we think that it is important to determine the contribution of these different kinds of representations in *the real-time writing to dictation of known words*. To achieve this aim, we have relied on multiple regression analyses that include all the essential variables that might be expected to have an effect on written latencies. In direct relation to the available spelling/writing to dictation models presented above, we thought it appropriate to include the variables that are generally thought to be true markers of the involvement of the different kinds of representations in question, i.e., semantic, lexical and sublexical representations. More precisely, regression analyses were performed on the written latencies of 164 words to delineate the variables that might contribute to the written onset latencies. The variables that we considered worth examining were, as far as possible, chosen for their reliability in indexing these representations.

We considered PO consistency to be a valid variable because consistency effects are generally taken to be true markers of the involvement of sublexical codes (Berent, 1997; Ziegler & Ferrand, 1998). The consistency measures used here were taken from the LEXOP database (Peereman & Content, 1999) (see the Material section for selection details). The finding of a contribution of PO consistency in multiple regression analyses would lend further support to the idea that sublexical knowledge truly contributes to writing performance on known words in adults. In word reading, it has been found that consistency/regularity effects are more easily obtained on low-frequency than on high-frequency words (e.g., Paap & Noel, 1991; Seidenberg, Waters, Barnes, & Tanenhaus, 1984; Taraban & McClelland, 1987). As far as spelling to dictation is concerned, as already mentioned, evidence for an interaction between word frequency and irregularity/consistency has been provided by Kreiner (1996).

The "lexical" variables included in the analyses were age-of-acquisition (AoA) and word frequency. AoA and word frequency are generally thought to index lexical representations (Jescheniak & Levelt, 1994; Morrison et al., 1992; Morrison, Hirsh, Chappell, & Ellis, in press). We included both variables in the light of a recent controversy surrounding word frequency effects. In effect, in the field of spoken picture naming it has been claimed for some years that AoA, but not word frequency, is the key variable (Morrison et al., 1992). However, some other studies have reported both AoA and word frequency effects (Barry et al., 1997; Brysbaert, Lange, & Van Wijnendaele, 2000; Ellis & Morrison, 1998) whereas recent studies in picture naming have found no frequency effect for sets of items matched on AoA (Barry, Hirsh, Johnston, & Williams, 2001; Bonin, Fayol, & Chalard, 2001). Although AoA has been found to affect the accuracy of the written production of a brain-damaged patient (Hirsh & Ellis, 1994) and the speed of written picture naming in normals (Bonin et al., 2001, 2002), we are not aware of any previous report of AoA effects on the speed of writing to dictation in normals. Moreover, it is important to emphasize that the dual-route view has not taken AoA into account even in one of its most recent versions (Rapp et al., 2002). The finding of a contribution of either AoA or word frequency or both in the written latencies would indicate the involvement of lexical representations in writing to dictation in normals.

To index semantic representations, we included imageability. In word reading, imageability effects are assumed to signal the involvement of semantics (Cortese, Simpson, & Woolsey, 1997; Plaut & Shallice, 1993; Strain & Herdman, 1999; Strain, Patterson, & Seidenberg, 1995, 2002; van Hell & de Groot, 1998). Imageability effects have been reported in visual lexical decision (Kroll & Merves, 1986; Morrison & Ellis, 2000; van Hell & de Groot, 1998). In word reading, Strain et al. (1995) have suggested that the effect of imageability is essentially observed on low-frequency irregular/inconsistent words (see also, Strain & Herdman, 1999). According to Strain et al. semantics are automatically accessed for all words but the phonological processing of regular/consistent words and high-frequency words is too efficient to allow semantic codes to make much impact. Semantics can assist in the computation of phonology when this computation is slow as for irregular/inconsistent low-frequency words. Reading aloud bears some close similarity with writing to dictation since, at a general level, the former involves the computation of phonological codes from orthographic codes whereas the latter involves the "inverse" mapping. Therefore, the examination of the three-way interaction between imageability, PO consistency and word frequency is relevant to spelling/writing to dictation but has never been reported before. Accordingly, a regression analysis was performed to examine this interaction. More precisely, based on Strain et al.'s findings, we predicted that the effect of imageability would be observed essentially on low-frequency/inconsistent words.

Recently, Monaghan and Ellis (2002) found that AoA, word frequency and imageability all interact with OP consistency in word reading. Moreover, Ellis and Monaghan (2002) have called into question previously reported imageability effects in word reading on the basis of the failure of these studies to take AoA into account. However, Ellis and Monaghan (2002) did not test the three-way interaction between AoA, consistency and imageability in word reading. A regression analysis was performed to test this interaction in writing to dictation.

Again on the basis of Strain et al.'s reasoning and findings, we anticipated that imageability should especially affect late-acquired/inconsistent words.

Some variables were also included in the regression analyses on account of their potential to reveal the contribution of the "input" and "output" components, respectively, that are involved in writing to dictation. On the input side, we included a neighborhood variable – number of phonological neighbors – in the light of some recent findings that have shown that auditorily presented words that have a dense neighborhood are processed more slowly than words with a sparse neighborhood (Vitevitch & Luce, 1998, 1999; Vitevitch, Luce, Pisoni, & Auer, 1999). We also considered the acoustic duration of the auditory item (in ms). On the output side, orthographic length defined as the number of letters was included.

METHOD

Participants

A total of 30 undergraduate students from Blaise Pascal University (Clermont-Ferrand) participated in the experiment in order to fulfil a course requirement and were given course credits. All were native speakers of French with normal or corrected-to-normal vision, and no known hearing deficit.

Material

The original stimuli consisted of 168 nouns. All the stimuli were monosyllabic words. The word stimuli were selected from the LEXOP lexical database (Peereman & Content, 1999). The items were recorded by a female speaker and digitized using 16-bit analog-to-digital conversion at a sampling rate of 44.1 with the SoundEdit software on a Macintosh computer. The word frequency values were taken from the LEXIQUE database which provides recent frequency counts for the French language based on a large corpus of 31 million words (New, Pallier, Matos, & Ferrand, 2001). The AoA values were selected from Alario and Ferrand (1999) and from Bonin, Peereman, Malardier, Méot and Chalard (in press). PO consistency measures and number of phonological neighbors were taken from the LEXOP database (Peereman & Content, 1999). We included PO consistency measures defined over final word units (the rime: VC). We chose this particular kind of PO consistency measure in the light of recent studies of our own (Bonin, Peereman, & Fayol, 2001; Peereman, Content, & Bonin, 1998) in which inconsistency defined over final units (VC) was found to have a strong detrimental effect on adults' writing to dictation performance. Also, for our data, PO consistency defined on rime units appeared to be a more reliable index of consistency than PO consistency defined over initial word units. Indeed, PO consistency on word-initial units is defined by considering PO consistency on the initial consonant or initial vowel. It appeared that this measure of PO consistency had a bimodal distribution: a large number of words had very high consistency values and very few had low consistency values. Imageability norms were taken from the Bonin, Méot, Aubert, Malardier, Niedenthal and Capell-Toczeck (under revision) study. Imageability norms were obtained in close adherence to the instructions provided by Paivio, Yuille and Madigan (1968). The participants had to rate on a 5-point scale how easily each word arouses a mental image with 1 = arouses a mental image with great difficulty or does not arouse a mental image, and 5 = arouses a mental image very easily. The entire set of experimental stimuli is provided in the Appendix. The statistical characteristics of the words are presented in Table 1.

Table 1. Statistical Characteristics of the Independent Variables Corresponding to the Item Used in the Regression Analyses

	AD	Ol	PN	Imag	AoA	Freq	POF
M	906.79	4.83	8.41	4.26	2.38	1.23	57.11
SD	173.11	.92	5.95	.51	.73	.58	34.46
Min	372	2	0	2.60	1.12	.12	2
Max	1349	7	23	4.96	4.30	2.78	100

Notes. M = mean; SD = standard deviation; AD = acoustic duration (ms); Ol = orthographic length; PN = number of phonological neighbors; Imag = imageability; AoA = age-of-acquisition; Freq = objective word frequency (log-transformed); POF = phonology-to-orthography consistency of final units (rime units)

Apparatus

The experiment was run using PsyScope (Cohen, MacWhinney, Flatt, & Provost, 1993) on a PowerMacintosh. The computer controlled the presentation of the auditory items and recorded the latencies. A graphic tablet (WACOM UltraPad A5) and a contact pen (SP-401) were used to record the graphic latencies. The latencies were recorded to an accuracy of the nearest millisecond. Twenty items were used as warm-ups.

Procedure

The participants were tested individually. The experimental session started with 20 practise trials. Each trial began with a visual ready signal (*) presented for 1000 ms in the center of a computer screen. It was followed, 200 ms later, by the auditory stimulus word presented through headphones. The intertrial interval was five seconds. The participants were required to write down the stimulus as quickly as possible on the graphic tablet using a contact pen. They were told to write down a cross when the stimulus was not identified. The participants were instructed that after responding they should immediately concentrate on the center of the screen. The time that elapsed between the onset of the spoken word and the contact of the pen with the graphic tablet was recorded by the computer. More precisely, the written responses were timed as follows: The participants sat with the stylus right above the tablet so that the latency was the time taken to make contact after item onset. In order to avoid any variability in the positioning of the stylus before each word was written, a line was drawn and the participant was obliged to position the stylus directly above the start of the line. We prepared response sheets (size: 21 x 29.7 cm) to enable us to gather all the written responses relating to the different words. These response sheets consisted of three columns of 20 lines each, with the different lines drawn one above the other at a constant interval of 1 cm. All of the lines were 5 cm long. The experimenter systematically ensured that the instructions were adhered to and always corrected the participants if they failed to observe them.

After completion of the experimental session, the participants were shown the entire list of experimental words on a sheet of paper. They were asked to circle each word for which they did not know either the meaning or the written or spoken form. All the words turned out to be known by the participants.

RESULTS

Scoring of the Data

Four items that had an error rate equal to or greater than 50% were removed from the latency data ("*cintre*", "*hyène*", "*clef*", and "*serpe*"). For the remaining items (164), trials were eliminated on the following basis. Trials for which words were misheard (0.16%), and words which were misspelled (3.56%) were removed from the latency data. Trials in which technical problems occurred were also discarded (0.85%). On the basis of this set of criteria, 4.57% of the trials were removed from the latency analyses. Finally, latencies exceeding two standard deviations above the item means were excluded (4.67%). Overall, 9.25% of the trials were discarded.

In all the analyses, written onset latency (in ms) was the dependent variable.[2]

ANALYSES

Written latency data for individual items in the stimulus set can be found in the Appendix.

Word frequency measures were transformed to log(freq + 1).

Table 2. Correlations between the Variables. Significant Correlations (P < .05) are Indicated in Bold

	WL	AD	Ol	PN	Imag	AoA	Freq
AD	**.543**						
Ol	.101	**.404**					
PN	-.138	**-.304**	**-.416**				
Imag	**-.225**	-.001	**-.188**	.080			
AoA	**.435**	.044	.131	**-.281**	**-.598**		
Freq	**-.288**	.012	-.100	.151	**.238**	**-.522**	
POF	.061	**.401**	**.399**	**-.424**	-.073	.072	-.086

Notes. WL = writtten latencies; AD = acoustic duration (ms); Ol = orthographic length; PN = number of phonological neighbors; Imag = imageability; AoA = age-of-acquisition; Freq = objective word frequency; POF = phonology-to-orthography consistency of final units (rime units)

[2] We do not make the strong assumption that "full" processing has taken place before writing onset. We acknowledge that future research will have to investigate which (if any) cognitive processes are reflected in the writing durations. However, this issue goes beyond the scope of the present study.

Table 2 shows the intercorrelations between the variables. The independent variable that had the highest correlation with written latencies was acoustic duration, followed by AoA and, to a lesser extent, word frequency and imageability.

Multiple Regression 1: Independent Effects

A first analysis was conducted to study the main effects on the written latencies of the following independent variables: acoustic duration, orthographic length, number of phonological neighbors, imageability, AoA, objective word frequency and PO consistency of final units.

The overall equation given by the simultaneous regression analysis using all the independent variables was significant, $F(7, 156) = 25.70$, $R^2 = .54$, $p < .001$.

Table 3. Summary of Multiple Regression Analysis 1

	β	SE	t	p
AD	.671	.063	10.65	.001
Ol	-.144	.066	-2.18	.03
PN	.064	.067	.96	.34
Imag	-.011	.071	-.15	.88
AoA	.377	.082	4.60	.001
Freq	-.134	.065	-2.07	.04
POF	-.162	.065	-2.49	.01

Notes. AD = acoustic duration (ms); Ol = orthographic length; PN = number of phonological neighbors; Imag = imageability; AoA = age-of-acquisition; Freq = objective word frequency; POF = phonology-to-orthography consistency of final units (rime units)

Table 3 shows that the variables that had significant effects were acoustic duration, AoA, orthographic length, PO consistency and word frequency.

Multiple Regression 2: Word Frequency X Imageability X PO Consistency Interaction

To examine the three-way interaction between imageability, word frequency and PO consistency, a term was formed by multiplying the three standardized predictors (Aiken & West, 1991) corresponding to word frequency, imageability and PO consistency. All first order interaction terms were also included in the equation.

The overall equation was significant, $F(11, 152) = 18.75$, $R^2 = .58$, $p < .001$.

As shown in Table 4, the percentage of explained variance was approximately the same as in the preceding regressions and the previously reported main effects were again significant. Importantly, the three-way interaction between word frequency, PO consistency and imageability was significant. The procedure suggested by Aiken and West (1991) was applied to test the simple slope of imageability for words with low frequency and low PO consistency values (i.e., one standard deviation below the frequency and PO consistency means). This slope was significant, $\beta = -.29$, $t = -2.49$, $p < .05$. Post-hoc tests indicated that imageability was not significant for other combinations of levels of word frequency and PO consistency. Also, post-hoc tests of the simple effects for each of the independent variables figuring in the interaction term with the two other independent variables fixed at low and/or high levels (i.e., one standard deviation below or above their means) revealed that the effect of PO consistency was significant for low-frequency/low-imageability words only, $\beta = -.42$, $t = -3.96$, $p < .001$, whereas frequency was significant only for low imageability/low PO consistency, $\beta = -.51$, $t = -3.7$, $p < .001$.

Table 4. Summary of Multiple Regression Analysis 2

	β	SE	t	p
AD	.692	.062	11.24	.001
Ol	-.137	.065	-2.12	.04
PN	.039	.065	.60	.55
Imag	.031	.071	.44	.66
AoA	.381	.080	4.79	.001
Freq	-.163	.067	-2.45	.02
POF	-.132	.064	-2.06	.04
Imag x Freq	.117	.053	2.19	.03
Imag x POF	.051	.061	.83	.41
Freq x POF	.080	.056	1.41	.16
Imag x Freq x POF	-.155	.052	-2.97	.001

Notes. AD = acoustic duration (ms); Ol = orthographic length; PN = number of phonological neighbors; Imag = imageability; AoA = age-of-acquisition; Freq = objective word frequency; POF = phonology-to-orthography consistency of final units (rime units)

Multiple Regression 3: AoA X Imageability X PO Consistency Interaction

To examine a three-way interaction between AoA, imageability and PO consistency, a term was formed by multiplying the three standardized predictors corresponding to AoA, imageability and PO consistency. All first order interaction terms were also included in the equation as in the preceding regression analysis.

The overall equation was significant, $F(11, 152) = 18.29$, $R^2 = .57$, $p < .001$.

With the exception of PO consistency, the same independent variables as in the preceding analyses were significant. An important result was that the three-way interaction was significant. As predicted, the test of the simple slope of imageability for late acquired/low PO consistency words was significant, $\beta = -.29$, $t = -2.50$, $p < .05$. Post hoc tests of the other simple slopes of the independent variables figuring in the interaction term revealed that imageability was not significant for other combinations of levels of AoA and PO consistency, PO consistency was significant for late acquired/ low imageability words only, $\beta = -.28$, $t = -3.07$, $p < .01$, and AoA was significant for low imageability/ low or high consistency words, $\beta = .56$, $t = 4.72$, $p < .001$ and $\beta = .33$, $t = -2.29$, $p < .05$, and also for words with high imageability/high PO consistency, $\beta = .44$, $t = 2.90$, $p < .01$.

Table 5. Summary of Multiple Regression Analysis 3

	β	SE	t	p
AD	.685	.062	11.08	.001
Ol	-.170	.066	-2.60	.01
PN	.022	.068	.32	.75
Imag	-.002	.073	-.03	.98
AoA	.362	.082	4.44	.001
Freq	-.139	.066	-2.10	.04
POF	-.105	.068	-1.54	.12
Imag x AoA	-.085	.054	-1.59	.11
Imag x POF	.063	.074	.85	.40
AoA x POF	.022	.070	.31	.75
Imag x AoA x POF	.139	.062	2.23	.03

Notes: AD = acoustic duration (ms); Ol = orthographic length; PN = number of phonological neighbors; Imag = imageability; AoA = age-of-acquisition; Freq = objective word frequency; POF = phonology-to-orthography consistency of final units (rime units).

Discussion

The aim of the present study was to delineate some of the variables that may be critical for written latencies in writing to dictation in normals in an attempt to determine the contribution of the different kinds of representations that underlie this cognitive activity.

In the light of some versions of the dual-route view of spelling to dictation (Ellis, 1982, 1984, 1988; Kreiner, 1992; Kreiner & Gough, 1990; Margolin, 1984; Rapp et al., 2002; Véronis, 1988), we anticipated that lexical as well as sublexical variables would make a reliable contribution to writing performance in normal adults. A series of three multiple regression analyses performed on the written latencies of 164 monosyllabic words revealed that the acoustic duration of the item, AoA, word frequency, PO consistency and orthographic length were reliable determinants of onset spelling latencies. Furthermore, we found that AoA, imageability and PO consistency interacted as well as word frequency, imageability and PO consistency.

Independent Effects

Acoustic Duration, Number of Phonological Neighbors and Orthographic Length

Acoustic duration was found to have a strong impact on the spelling latencies. This finding however, does not come as a surprise. In effect, since the input is auditorily presented, it is delivered to the cognitive system in a sequential manner. Thus, words which have a longer acoustic duration take longer to be auditorily processed than words that have a shorter acoustic duration, and these differences are reflected in the spelling latencies. The significant correlation between acoustic duration and spelling latencies suggests that participants start writing when the "full" auditory string (or at least a substantial proportion of it) string has been made available. It cannot be argued that acoustic duration is indeed a phoneme length effect because in regression analyses that included number of phonemes as a predictor, with or without acoustic duration entered into the regression model, the number of phonemes was not significant.

The number of phonological neighbors was not found to exert a significant independent contribution. This observation contrasts with previous findings in the auditory word recognition domain which have shown that words with a dense neighborhood are processed more slowly than words with a sparse neighborhood (Vitevitch & Luce, 1998, 1999; Vitevitch et al., 1999).

Orthographic length was also found to exert an effect on the latencies. The effect was rather surprising since it indicates that the longer the words, the shorter the written latencies. Due to the observation that the regression analysis including number of phonemes as a predictor reported aboved reveals that orthographic length was still reliable, orthographic length is presumably a pure output effect. However, to provide a clear account of this effect, orthographic length should be investigated more systematically in future work.

Age Of Acquisition, Word Frequency and PO Consistency

The finding that lexical variables – AoA and word frequency – together with a sublexical variable – PO consistency of final units – significantly contribute to the written latencies in normal adults lends clear empirical support to views of spelling to dictation that have claimed that lexical as well as sublexical knowledge contributes to spelling performance, such as Rapp et al.'s (2002) model in which sublexical and lexical information is integrated at the grapheme level.

The finding that PO consistency has an impact in writing to dictation replicates previous observations of our own (Bonin, Peereman, & Fayol, 2001; Peereman et al., 1998). If the assumption that consistency truly indexes sublexical representation is followed (Berent, 1997; Ziegler & Ferrand, 1998), then the observation that a consistency variable has a detrimental effect on adults' performance in writing to dictation effectively rules out versions of the dual-route view of spelling which have considered the sublexical route as optional, and which, therefore, claim that word spelling to dictation in normals is primarily achieved on the basis of the lexical route (Kreiner, 1992; Véronis, 1988).

The findings are thus compatible with views that allow both sublexical and lexical codes to play a role in orthographic encoding in spelling to dictation. More precisely, the data are compatible with models which postulate some form of integration of sublexical and lexical processes such as Rapp et al.'s (2002) model.

The observation that AoA contributes to spelling latencies adds further support to the studies that have shown that this variable is an important one in various lexical processing tasks (e.g., Barry et al., 1997, 2001; Brown & Watson, 1987; Carroll & White, 1973; Coltheart, Laxon, & Keating, 1988; Gerhand & Barry, 1998; Gilhooly & Logie, 1981a, 1981b; Morrison et al., 1997; Morrison et al., 1992). As claimed in the Introduction, the finding of an AoA effect in real-time writing to dictation in normals has not been reported before and is not predicted by dual-route models since they have not incorporated AoA. So far, establishing a precise locus for AoA effects in word processing has not proven to be an easy task. The commonly held hypothesis has been that the locus of AoA is to be found at the level of the retrieval of *lexical phonology* (e.g., Barry et al., 2001; Morrison et al., 1992, in press). If one adheres to the hypothesis that lexical phonology underlies the emergence of AoA effects, then the finding of a contribution of an AoA effect in writing to dictation would be due to the fact that *lexical* phonological representations are consulted in this task. While it is obviously the case that input phonology is involved in spelling/writing to dictation given that the auditory string provides the initial source of phonological activation, in terms of the models reviewed in the Introduction that distinguish between input and output phonology the issue of the locus of AoA becomes somewhat complex. Given that AoA effects are robustly found in "output" tasks such as spoken picture naming (Barry et al., 1997, 2001; Bonin, Fayol, & Chalard, 2001; Carroll & White, 1973; Hodgson & Ellis, 1998; Morrison et al., 1997; Morrison et al., 1992), one might well suggest that AoA effects in spelling are localized at the level of output phonology. In Rapp et al.'s (2002) model of spelling to dictation, the phoneme level sends activation to the phonological lexeme level, which, in turn, sends activation to the semantic system and then to orthographic lexemes. In this modeling of spelling to dictation, AoA effects might arise at the phonological lexeme level. Finally, an alternative explanation might be that AoA affects not only the (output) phonological representations but all stages of word processing (Ellis & Lambon Ralph, 2000; Gerhand & Barry, 1999).

One problem with the dual-route view, however, is that it says nothing about how the architecture develops in response to training and experience. In word reading, the most proeminent dual-route model, the DRC model (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001), has a static structure that is programmed by the modeler. Coltheart et al. have claimed that their model might be extended to spelling to dictation but it remains to be seen whether (1) this model could account for AoA effects if it was implemented to learn words and whether (2) AoA effects would be more likely to derive selectively from different components of the model.

As far as connectionist models of spelling to dictation are concerned, as already mentioned, they are, to some extent, at an early stage of development (e.g., Brown & Loosemore, 1994; Houghton et al., 1994). In their present form, these specific models cannot account for AoA effects as observed in the present study since they were not intended to simulate AoA effects. For instance, in Brown and Loosemore's (1994) connectionist model, the "vocabulary" patterns were entered together into training. Therefore, since the order of entry of the vocabulary was not implemented, the model cannot simulate AoA effects in its present form. To our knowledge, until now, the connectionist framework proposed by Ellis and Lambon Ralph (2000) has provided an account for both AoA and word frequency. Ellis and Lambon Ralph (2000) showed that distributed connectionist networks trained by backpropagation are able to simulate the effects of AoA and word frequency when the patterns are entered into training at different points and when learning is cumulative and interleaved. According to Ellis and Lambon Ralph (2000), AoA and word frequency effects are a natural property of such networks. These effects are explained in the same way: They are due to a gradual reduction of the network plasticity and a consequent failure in differentiating late/low-frequency items as effectively as early/high-frequency ones. However, the simulations provided by Ellis and Lambon Ralph (2000) used abstract patterns and were presented as a demonstration of principle. It remains to be seen how this type of network, altered in order to implement the relationship between phonological and orthographic codes reliably, could account for AoA (and word frequency) effects in spelling/writing to dictation.

The important point here is that AoA – which is widely acknowledged as being a lexical variable – makes a strong contribution in writing to dictation, and thus clearly indicates the importance of lexical knowledge in word spelling in normals.

As reviewed in the Introduction, word frequency, in addition to AoA, was introduced as a predictor of written latencies in the light of certain controversies surrounding word frequency effects. We found a significant independent contribution of word frequency. This finding is in line with others which have identified effects of both variables in several word processing tasks (e.g., Ellis & Morrison, 1998; Gerhand & Barry, 1999). The finding that word frequency plays a significant role in predicting written latencies adds to the view that lexical knowledge is involved in writing to dictation, since this variable has most often been recognized as a lexical variable. Word frequency effects are clearly predicted by both the dual-route approach and the connectionist approach of spelling to dictation. The dual-route view localizes frequency effects within the lexical route and more precisely at, or around, the levels of the orthographic and phonological lexicons (e.g., Coltheart et al., 2000 in word reading). In contrast, word frequency effects in connectionist networks are encoded in the strength of the connections relating different kinds of representations (e.g., Plaut, McClelland, Seidenberg, & Patterson, 1996; Seidenberg & McClelland, 1989).

Imageability

The semantic variable that was considered – imageability – was not found to make a significant independent contribution in predicting the spelling latencies. However, imageability interacted significantly with PO consistency and word frequency/AoA as we discuss below. It is important to stress, as claimed by Strain et al. (2002), that connectionist models of word reading such as Seidenberg and McClelland's (1989) do not specifically predict an independent effect of imageability but rather an interaction between imageability, consistency and word frequency.

Three-way Interactions

A number of regression analyses were performed to test the three-way interaction between imageability, word frequency and PO consistency in writing to dictation due to certain findings in the reading literature that suggest that semantics primarily influence the computation of low-frequency words having irregular/inconsistent OP mappings (Strain et al., 1995). We also examined whether imageability interacted with AoA and PO consistency since Strain et al. did not control for AoA. These two three-way interactions turned out to be significant. As far as the three-way interaction between word frequency, imageability and consistency is concerned, the similarity of our findings with those of Strain et al. is striking. The interaction effects found in the present study are valuable since they place *strong* additional constraints on the modeling of writing to dictation in normals.

Dual-route models are able to account for the interaction between word frequency and PO consistency. In effect, in dual-route models, two routes are involved in the building of orthographic codes for spelling words: a sublexical conversion procedure and a lexical procedure. As reviewed in the Introduction, there is strong evidence that the two routes integrate information at a common level of representation, for instance at the grapheme level in Rapp et al.'s (2002) model. In such dual-route models of spelling to dictation, more conflict between the two routes is thought to arise in the case of low- than high-frequency words. More precisely, elaborating on Rapp et al.'s model of spelling to dication, if we assume that word frequency is encoded at both the phonological lexeme and orthographic lexeme levels (note that Rapp et al. did not provide details concerning the locus(loci) of word frequency effects in spelling to dictation), then because the amount of activation that is passed from the phonological lexeme level to the orthographic level is proportional to the frequency of each word in the language, more conflict between the routes arises for low- than for high-frequency words. High-frequency words in the phonological lexicon activate their corresponding orthographic representations via the semantic system more strongly, with the result that the lexical route provides information at the graphème level more efficiently, that is to say activation arrives faster at the grapheme level – and before activation coming from the sublexical route – than in the case of low-frequency words. Therefore, the lexical route for high-frequency words is affected only slightly by rival activation coming from the sublexical route. In contrast, for low-frequency inconsistent words, the lexical and the sublexical routes converge on the grapheme level at about the same time, creating a conflict that requires additional time to be resolved. Turning now to the three-way interaction between imageability, word frequency and consistency, dual-route models can account for this interaction provided that they assume a semantic-lexical pathway. In word reading, in addition to a direct orthographic-to-phonological pathway, an orthographic-semantic-phonological pathway is included in the DRC model (Coltheart et al., 2001) but this route has not as yet been implemented. In Rapp et al.'s spelling-to-dictation model, a direct lexical route between phonology and orthography is not explicitly represented. The phonemes derived from the analysis of the auditory string activate phonological lexemes, which are mapped to semantic representations. In turn, semantic representations are mapped to orthographic lexemes. However, the present findings force us to suggest that a direct lexical route should be included in this modeling of the spelling/writing process.

As far as connectionist models are concerned, and again in word reading, the interaction between word frequency, consistency and imageability has been accounted for by Strain et al. (1995) in terms of the connectionist model proposed by Seidenberg and McClelland (1989) (see also, Plaut et al., 1996). In such models, word reading is an interactive process which associates orthographic units with phonological units. The model also assumes interactivity between phonology, orthography and semantics. Thus, semantic codes can affect the computation of phonology. According to Strain et al., the effect of semantic activation on phonological computation is especially strong when the computation is slow as is the case for inconsistent words. In contrast to high-imageable words, low-imageable inconsistent words do not have rich semantic representations and thus do not benefit from semantics in the same way as high-imageable words. As far as consistent words are concerned, the computation of phonology is fast and the effect of imageability is diminished. This account can be extended to spelling/writing to dictation given that at a macroscopic level, the two tasks have some close similarities since reading aloud involves mapping orthography to phonology whereas spelling to dictation involves mapping phonology to orthography. Therefore, the idea that the same functional principles are involved in the two tasks does not seem unreasonable.

As far as the imageability, AoA and PO consistency interaction is concerned, accounting for this interaction within the dual-route framework is somewhat complex. In effect, although word frequency is echoed in dual-route models, so far, to our knowledge, AoA has not been taken into account in the modeling of spelling to dictation within the dual-route framework.

Moreover, dual-route models have a "static" structure. It remains to be seen how such models could account for such an interaction if they were implemented to learn words in a cumulative and interleaved fashion. As far as the connectionist approach is concerned, as already said, it has not generally taken AoA into account. In the word reading domain, Zevin and Seidenberg (in press) have recently shown that connectionist models which reliably implement spelling-sound relationships (which are quasi-regular in most alphabetic languages) do not reveal AoA effects. Monaghan and Ellis (2002) have shown that connectionist networks in which learning is cumulative and interleaved are able to simulate the interactions of both AoA and word frequency with OP consistency. These interactions can be understood in terms of a connectionist framework in which late-acquired items (or low-frequency items) can be assimilated easily if they are able to take advantage of the network structure generated by early-acquired and/or high-frequency items. Consistent items are also advantaged because they can use the same links as other consistent ones, whereas inconsistent items require unique mappings to be established. It is important to stress that the type of networks and the patterns used by Monaghan and Ellis (2002) are intended to be broadly analoguous to, but not close simulations of, word reading aloud, as the authors have acknowledged. However, given that the simulations only incorporated arbitary patterns and did not reliably implement the relationships between semantic, phonological and orthographic codes, it remains to be seen therefore how such connectionist networks applied to spelling/writing to dictation could account for the interaction between imageability, AoA and consistency.

To conclude, our study makes a valuable contribution in showing that sublexical as well as lexical knowledge is contacted during the on-line written spelling of known words in adults. Also, it shows that the impact of semantic representations is essentially seen when the computation of orthography from phonology is slow as is the case for low-frequency/late-acquired, low-imageability words. Therefore, our study suggests that semantics influence orthographic encoding from phonology. Our study agrees with dual-route models of spelling to dictation that, so far, have essentially been based on analyses of the performances of brain-damaged patients, and that hold that spelling to dictation involves some form of integration of both lexical and sublexical processes (Rapp et al., 2002), even though the functional details remain to be identified in future research in order to provide a full account, within the dual-route view, of the complex pattern of interactions between AoA/word frequency, imageability and PO consistency reported here. The finding of an interaction between word frequency, imageability and consistency accords with some connectionist models (e.g., Seidenberg & McClelland, 1989) but the interaction between AoA, imageability and PO consistency is thus far not accounted for by the connectionist approch. As this is the case for the dual-route view, more work is needed to provide a full account of the findings reported here. The present study highlights the need to examine writing to dictation by means of real-time paradigms if we are to gain a greater understanding of the cognitive processes involved in this task in normals since, as we have shown, it helps to delineate the constraints that will have to be taken into account in the modeling of the spelling process.

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AUTHORS' NOTE

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APPENDIX

Mean spelling latencies (SL in ms) and standard deviations of these means (SD_S); number of observations (Nb Obs) used in the calculation of the means and standard deviations for the stimuli used in the experiment. The four items that were discarded from the latency analyses are not listed.

Item	English translation	SL	SD_S	Nb Obs
aigle	eagle	1165	133	28
âne	donkey	1139	138	29
ange	angel	1040	155	28
anse	handle	1216	279	16
arbre	tree	1314	276	30
bague	ring	1251	176	28
banc	bench	1115	201	28
barbe	beard	1270	132	28
bec	beak	1223	144	27
biche	deer	1104	158	28
blé	wheat	1253	197	28
boîte	box	1225	133	29
bol	bowl	1022	137	25
bombe	bomb	1085	160	28
borne	milestone	1151	166	30
bosse	bump	1055	153	27

Item	English translation	SL	SD_S	Nb Obs
bouche	mouth	1226	181	28
bouée	lifebuoy	1129	177	18
boule	ball	1211	169	28
branche	branch	1002	137	27
bras	arm	1036	191	29
brique	brick	1281	161	26
brosse	brush	1065	182	27
bulle	bubble	1207	179	28
bus	bus	1202	170	28
cadre	frame	1180	186	29
cage	cage	1157	135	28
caisse	crate	1066	216	29
carte	playing card	1129	145	26
casque	helmet	1224	127	29
cercle	circle	1273	104	29
chaise	chair	1208	187	28
chat	cat	1206	152	28
chèvre	goat	1203	191	28
chien	dog	1260	178	30
chope	beer mug	1314	271	25
cible	dart board	1359	218	29
cloche	bell	1084	160	29
clou	nail	1105	204	27
clown	clown	1000	135	26
coffre	chest	1172	120	26
corde	rope	1142	161	28
corne	horn	1114	178	28
coupe	cup	1024	175	29
crabe	crab	1030	180	29
crâne	skull	1308	180	28
crèche	crib	1055	148	29
crêpe	pancake	1057	180	28
crête	comb (of cock)	1278	212	28
croix	cross	1002	194	28
cube	cube	919	116	27
diable	devil	1173	197	29
disque	record	1120	180	28
doigt	finger	1098	130	27
douche	showerhead	1034	210	27
drap	sheet	1010	162	27
druide	druid	1194	233	29
faon	fawn	1266	355	20
fée	fairy	1031	149	29
femme	women	1043	150	28

Item	English translation	SL	SDs	Nb Obs
feu	fire	1022	175	29
feuille	leaf	955	164	29
fille	girl	971	121	29
fleur	flower	1169	176	29
fouet	whip	1274	196	27
fraise	strawberry	1147	173	29
gant	glove	1201	187	27
gland	accorn	1170	160	25
globe	globe	1198	171	28
gomme	eraser	1086	163	29
gourde	(water) flask	1210	262	29
goutte	drop	1241	173	25
grange	barn	1153	200	28
griffe	claw	1196	166	27
groupe	group	1064	130	27
hache	axe	1159	286	26
harpe	harp	1311	196	24
huître	oyster	1331	216	29
île	island	1070	177	28
jambe	leg	1209	183	27
jeep	jeep	1345	262	23
jupe	skirt	1095	150	28
lampe	lamp	1071	252	29
langue	tongue	1239	193	29
larme	tear	1391	175	28
lettre	letter	1035	151	28
lime	nail file	1262	157	27
lion	lion	1065	176	28
lit	bed	1148	125	28
livre	book	1250	157	28
louche	ladle	1285	167	28
loupe	magnifying glass	1134	222	28
luge	sled	1148	183	27
lune	moon	1168	163	28
main	hand	1174	158	28
masque	mask	1243	189	27
mèche	drill bit	1125	190	28
monde	world	1239	201	27
morse	walrus	1139	226	26
moufle	mitten	1175	174	18
natte	plaits	1177	177	29
nez	nose	1212	172	29
niche	doghouse	1256	282	29
noeud	bow	1097	146	23

Item	English translation	SL	SD_S	Nb Obs
noix	walnut	1085	132	27
note	notes	1208	152	29
oeil	eye	1106	194	28
oeuf	egg	985	134	27
oie	goose	1325	239	24
ongle	nail	1152	172	27
orgue	organ	1302	262	28
os	bone	1130	154	29
ours	bear	1041	147	27
palme	flipper	1145	142	28
paume	palm	1156	173	18
peigne	comb	1188	174	27
pelle	dust pan	1036	187	22
phoque	seal	1198	291	25
pièce	coin	965	204	30
pied	foot	921	149	26
pince	pliers	1127	172	29
pion	pawn	1116	270	28
pipe	pipe	1007	126	28
plante	plant	1134	132	29
plat	dish	1079	210	29
plume	feather	998	102	28
pneu	tire	1085	152	28
poche	pocket	932	135	29
poire	pear	1005	225	27
pomme	apple	911	129	26
pont	bridge	933	168	27
porte	door	985	155	28
poule	chicken	1043	233	30
poulpe	octopus	1160	162	27
pré	meadow	1141	116	15
prise	plug	1319	166	27
puzzle	jigsaw-puzzle	1176	169	27
quille	skittle	1129	281	29
raie	ray	1333	246	27
rat	rat	1051	233	23
règle	ruler	1277	186	26
robe	dress	1046	187	23
rose	rose	1013	179	27
route	road	1146	173	29
sabre	sabre	1289	193	28
sac	bag	1130	155	29
singe	monkey	1273	156	29
sphinx	sphinx	1505	247	23

Item	English translation	SL	SD_S	Nb Obs
table	table	1036	149	29
tank	tank	1090	142	16
tasse	cup	997	168	28
taupe	mole	1188	163	28
tigre	tiger	1003	174	29
torche	flashlight	1170	197	29
train	train	917	161	28
trèfle	clover	1281	200	29
tronc	trunk	984	126	28
tuile	tile	1150	146	26
urne	urn	1170	186	25
vache	cow	968	135	28
vase	vase	1065	150	27
veste	jacket	945	167	29
voile	sail	1103	197	29
zèbre	zebra	1231	169	29