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Syllabic length effects in visual word recognition and naming

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Abstract

Two experiments investigated the role of the number of syllables in visual word recognition and naming. Experiment 1 (word and nonword naming) showed that effects of number of syllables on naming latencies were observed for nonwords and very low-frequency words but not for high-frequency words. In Experiment 2 (lexical decision), syllabic length effects were also obtained for very low-frequency words but not for high-frequency words and nonwords. These results suggest that visual word recognition and naming do require syllabic decomposition, at least for very low-frequency words in French. These data are compatible with the multiple-trace memory model for polysyllabic word reading [Psychol. Rev. 105 (1998) 678]. In this model, reading depends on the activity of two procedures: (1) a global procedure that operates in parallel across a letter string (and does not generate a strong syllabic length effect) and that is the predominant process in generating responses to high-frequency words, and (2) an analytic procedure that operates serially across a letter string (and generates a strong syllabic length effect) and that is the predominant process in generating responses to very low-frequency words. A modified version of the dual route cascaded model [Psychol. Rev. 108 (1) (2001) 204] can also explain the present results, provided that syllabic units are included in this model. However, the Parallel Distributed Processing model [Psychol. Rev. 96 (1989) 523; J. Exp. Psychol.: Human Perception Perform. 16 (1990) 92] has difficulties to account for these results.

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1. Introduction

Although a great deal is known about the processing of *monosyllabic words* (see for instance Coltheart, Curtis, Atkins, & Haller, 1993; Seidenberg & McClelland, 1989), very few studies have been devoted to the processing of *polysyllabic words* (see however, Ans, Carbonnel, & Valdois, 1998; Ferrand & Segui, 2003; Jared & Seidenberg, 1990). Indeed, most of the studies on complex words concern monosyllabic words. This is a paradox since monosyllabic words represent less than 10% of the lexicon and therefore can be considered as the exception, whereas polysyllabic words should be studied more extensively. The present article addresses explicitly the processes involved in the recognition of polysyllabic words and nonwords. In particular, we examined if the visual recognition and naming of polysyllabic stimuli depend on the number of the syllables they contain.

1.1. Previous studies on the syllable-length effect in visual word recognition and naming

The seminal work of Spoehr and Smith (1973) suggests that syllable-sized units play a role in visual word recognition. Subjects were presented with five-letter English words that were either one or two syllables long and that were matched in pairs for other variables such as frequency and number of vowels (e.g., PAINT and PAPER). These authors showed that report accuracy was significantly higher for one- than for two-syllable words. These results suggest that processing in this task proceeds syllable by syllable. Klapp (1971) also showed that response latency in a same–different task increased with the number of syllables in the items to be judged.

A large number of studies have also studied the syllable-length effect in naming, but these studies have yielded inconsistent results (see Ferrand & Segui, 2003; Henderson, 1982, for reviews). In their seminal study, Eriksen, Pollack, and Montague (1970) presented subjects with monosyllabic and trisyllabic words that were matched so that each monosyllabic word was the first syllable in a trisyllabic word (e.g., cab/cabinet). They found a significant effect of number of syllables on naming latency. However, the number of syllables was confounded with word length. In a later study, Klapp, Anderson, and Berrian (1973) found a significant effect of number of syllables when number of letters was constant. Using a delayed naming task, Klapp et al. found no difference in naming latency between one-syllable and two-syllable words, suggesting that the syllabic length effect is a phonological encoding effect, not an articulatory effect.

Despite these positive findings, other studies have reported no effect of the number of syllables on the initiation of word naming (e.g., Forster & Chambers, 1973; Frederiksen & Kroll, 1976). More recent research conducted by Jared and Seidenberg (1990) indicates, however, a possible source of discrepancy between the results mentioned above. According to Jared and Seidenberg, studies examining the effects of number of syllables on naming have yielded inconsistent results because none of these studies examined the interaction of word frequency and number of syllables on naming. In their Experiment 3, Jared and Seidenberg showed that the number of syllables in a word influenced naming latencies only for low-frequency words.

The authors interpreted this syllabic effect within the framework of the Parallel Distributed Processing (PDP) model developed by Seidenberg and McClelland (1989). According to Jared and Seidenberg (1990), an effect of number of syllables in naming does not necessarily mean that words are decomposed into syllables. The PDP model was used to describe how one might get syllable effects without explicit syllable units. They suggested that syllable effects might actually be spelling–sound consistency effects. Because each syllable must have a vowel, words with a greater number of syllables also have a greater number of vowels. In English (contrary to French) vowels are the greatest source of spelling–sound inconsistency (see Ziegler, Stone, & Jacobs, 1997). So words with more vowels have more sources of inconsistency than words with the same number of letters but fewer vowels. High-frequency words may not show a syllable effect either because the effects are attenuated by frequent exposure to the word, or because the high-frequency words have less inconsistent vowels than the low-frequency words used in Jared and Seidenberg's study.

Recently, one of us (Ferrand, 2000) re-examined whether there are equivalent or differential effects of number of syllables on the latency to name high-frequency words, low-frequency words, and nonwords in French. The first experiment was a replication of Jared and Seidenberg's experiment but with better controls in terms of initial syllable (items matched on the first syllable were used since Carreiras, Alvarez, & De Vega, 1993, found a syllable frequency effect on the initial syllable on naming), number of orthographic neighbors (hermits were used, i.e. words with no orthographic neighbors; Grainger, 1990) and syllabification (French stimuli with clear syllable boundaries were used). Furthermore, in order to rule out the possibility that the syllabic length effect was due to ease of articulation rather than the time taken to generate a phonological code, Ferrand (2000) conducted a control delayed naming task. In his second experiment, nonwords were used instead of words. The results obtained by Ferrand (2000) extend those of previous studies by showing that there are differential effects of number of syllables on word and nonword naming latency. In his Experiment 1 (words only), number of syllables had an effect only on low-frequency words (thus replicating Jared and Seidenberg's result). However, there was no effect of number of syllables for high-frequency words. In his Experiment 2 (nonwords only), the syllabic length effect was also observed with nonword stimuli. These effects were observed when items were matched for number of letters, number of phonemes, number of orthographic neighbors, bigram frequency, initial phoneme and initial syllable. Furthermore, there was no effect of number of syllables in a control delayed naming task suggesting that the syllabic length effect is a real phonological encoding effect and not an articulatory effect.

1.2. Three models of polysyllabic word reading

The syllabic length effect constitutes an interesting challenge for current models of visual word recognition and naming. Table 1 illustrates some of the main characteristics of the multiple-trace memory (MTM) model of polysyllabic word reading (Ans et al., 1998) contrasted with two other models, the dual route cascaded model (Coltheart et al., 1993, 2001) and the PDP model (Jared & Seidenberg, 1990; Seidenberg &

Table 1
Comparison of models of polysyllabic word reading

Characteristics	MTM model[a]	DRC model[b]	PDP model[c]
Distinction between a lexical route and a nonlexical route	Yes	Yes	No, single mechanism
Application of rules	No	Yes	No
Parallel processing	Yes, for high-frequency words via lexical route	Yes, for high-frequency words via lexical route	For all stimuli
Sequential reading mechanism	Yes, for nonwords and very low-frequency words	Yes, for nonwords and very low-frequency words	No
Strategic use of routes	No	Yes	No
Type of units	Syllables	Graphemes–phonemes	Triples of letters and phonetic features
Syllabic decomposition	For nonwords and very low-frequency words only	No, grapheme–phoneme conversion only[d]	No

[a] Ans et al. (1998).
[b] Coltheart, Rastle, Perry, Langdon, and Ziegler (2001).
[c] Jared and Seidenberg (1990).
[d] If graphemes–phonemes are replaced by graphemic syllables and phonemic syllables, DRC can assume a syllabic decomposition instead of a grapheme–phoneme decomposition.

McClelland, 1989). The comparison of these three models relies on seven important characteristics.

The first characteristic, whether the models recognize a distinction between a lexical route (or global procedure) and a nonlexical route (or analytic procedure), is included in the table. The MTM and DRC models share this feature, but not the PDP model. In contrast to the PDP model, the MTM model does not postulate that a single uniform procedure is used for generating the pronunciation of both words and nonwords. Rather, it is assumed that two types of procedures, a global and an analytic one, are required for processing all kinds of letter-strings. However, it cannot be viewed as simply another version of the DRC model since the global and analytic procedures do not work in parallel: global processing always proceeds first, the analytic procedure applying only secondarily when global processing has failed. Therefore, this distinction between a lexical route (or global route) and a nonlexical route (or analytic route) is one of the key differences between the MTM and DRC models, and the PDP model.

The second characteristic concerns the presence/absence of conversion rules. The MTM and PDP models can process all types of letter strings (including nonwords) solely on the basis of word knowledge and therefore without using a system of conversion rules, whereas the DRC model requires such a system, at least for nonwords and very low-frequency words. In particular, the MTM model does not retain the assumption that knowledge about spelling-to-sound correspondences is represented in terms of orthography-to-phonology conversion rules and that the pronunciation of nonwords is generated by application of these rules. Rather and more in line with the PDP model, it assumes that mapping from orthography to phonology only emerges from the integrated activation of previously experienced whole words and word syllabic segments.

The third and fourth characteristics concern the specific use of each route/procedure, namely the lexical/parallel/global procedure and the nonlexical/sequential/analytic procedure. Both MTM and DRC postulate that high-frequency words are processed via the lexical/parallel/global route, and that very low-frequency words and nonwords are processed via the nonlexical/sequential/analytic route. In contrast, the PDP model postulates a single parallel procedure to process all kinds of stimuli (including nonwords).

The fifth characteristic concerns the strategic use or not of routes/procedures. The DRC model postulates a strategic use of routes, in such a way that the lexical route can be deemphasized or turned down as more and more nonwords are encountered (simply because this route is never providing a correct response) whereas the nonlexical route is turned up (because this route is always providing the correct response), and the nonlexical route can be turned down as more and more words are processed whereas the lexical route is turned up. In contrast, the MTM model does not postulate such a strategic use of procedures, and we already saw that the PDP model does not make a distinction between two routes or procedures.

A sixth characteristic concerns the type of units used in these models. A unique property of the MTM model is that it contains explicit *syllable units*. The DRC model contains graphemes/phonemes whereas the PDP model does not contain symbolic units but rather triples of letters and triple of phonetic features.

The last characteristic concerns the presence/absence of a syllabic decomposition. The MTM model is the only one to possess this feature, the DRC model having only a grapheme–phoneme conversion system, and the PDP model having no equivalent.

1.3. The present study: predictions of the models

The aim of the present study was twofold. First, we wanted to test the syllabic length effect both in visual word recognition and naming. Second, we wanted to test the syllabic effect in naming using a mixed list (words and nonwords). In Ferrand's (2000) experiments, words and nonwords were not presented in a mixed list, so the subjects knew in advance whether an item would be a word or a nonword prior to presentation. Under these conditions, use of the analytic procedure (or the nonlexical route) may have been maximized in Experiment 2 (nonwords only) but minimized in Experiment 1 (words only), and the use of the global procedure (or the lexical route) may have been minimized in Experiment 2 and maximized in Experiment 1, inasmuch as these routes are under strategic control (DRC suggests that they are, whereas MTM and PDP suggest they are not; see Table 1). Experiment 1 was a replication of Ferrand's (2000) experiment but with a mixed list containing words and nonwords. In Experiment 2, subjects had to classify stimuli as words or nonwords instead of reading them aloud.

In Table 2, we present a clear set of predictions derived from the three models of reading polysyllabic words and nonwords presented previously (see Table 1). In

Table 2
Predicted effects according to models of polysyllabic word reading

	MTM model[a]	DRC model[b]	PDP model[c]
Naming			
Syllabic effects for high-frequency words	No	No	No
Syllabic effects for very low-frequency words	Yes[d]	In principle[e,f]	Yes[g]
Syllabic effects for nonwords	Yes[d]	In principle[e,f]	No
Lexical decision			
Syllabic effects for high-frequency words	No	No	No
Syllabic effects for very low-frequency words	Yes	In principle[e]	Yes
Syllabic effects for nonwords	No	No	No

[a] Ans et al. (1998).
[b] Coltheart et al. (2001).
[c] Jared and Seidenberg (1990).
[d] Syllabic effects should be of similar size in both mixed and pure lists since there is no strategic use of routes.
[e] Yes if graphemes–phonemes are replaced by graphemic syllables and phonemic syllables.
[f] Syllabic effects should be stronger in pure lists (emphasizing one of the two routes) than in mixed lists since routes are used strategically.
[g] This is due to the irregularity of the additional vowel; syllables are emergent properties of the model.

particular, the MTM model is the only one to predict clear syllabic length effects for both very low-frequency words and nonwords in naming, and for very low-frequency words in lexical decision. In this model, naming latencies should be longer for analytically than for globally processed printed stimuli since the analytic mode only applies after the global mode has failed. Therefore, an increase in naming latencies with syllabic length is predicted for nonwords since analytic processing is sequential, each syllable requiring a new visual capture of information. The MTM model also predicts a syllabic length effect for very low-frequency words since the analytic process applies to these stimuli. In other words, the MTM model is the only one allowing a syllabic decomposition for very low-frequency words and nonwords (see Table 2). Furthermore, the MTM model predicts the presence of syllabic effects even with mixed lists, since there is no strategic use of procedures, therefore no emphasizing or deemphasizing of one route or the other.

On the other hand, the DRC model does not predict any syllabic length effects either in naming or lexical decision, unless graphemes–phonemes are replaced by syllables. With this modification, the DRC model makes similar predictions as the MTM model for naming and lexical decision. However, because the stimuli are presented into a mixed list, and because the model allows a strategic use of routes, the syllabic length effects might be weaker with mixed lists than with pure lists in naming (see Table 2). The PDP model also predicts a syllabic length effect for very low-frequency words in naming and lexical decision, but this would be due to the irregularity of the additional vowel. In other words, syllables would be emergent properties of the model. Furthermore, the model does not predict an effect for nonword naming. All three models predict an absence of effect for high-frequency words in naming and lexical decision.

2. Experiments 1 (naming) and 2 (lexical decision)

2.1. Method

2.1.1. Subjects

Fifty-six psychology students at René Descartes University, Paris, France, served as subjects for course credit, 16 in the Experiment 1 (naming) and 40 in Experiment 2 (lexical decision). All were native speakers of French and had normal or corrected-to-normal vision.

2.1.2. Stimuli and design

For the naming task, the stimuli were taken from Ferrand (2000) and contained 80 French words, 40 high-frequency items and 40 very low-frequency items, and 40 nonwords. Half of the words and nonwords had two syllables, and the remaining half had three syllables. For the lexical decision task, the stimuli were 80 French words (exactly the same as in Experiment 1), 40 high-frequency items and 40 very low-frequency items. Half of the words had two syllables, and the remaining half had three syllables. Eighty nonwords were also used for the purpose of the lexical decision task (40 of these nonwords were taken from Experiment 1 and 40 new nonwords were added), half had two syllables, and the remaining half had three syllables. The nonwords were generated from French words by replacing a consonant with another consonant, or a vowel with another vowel. All the nonword stimuli had straightforward, unambiguous pronunciations following standard French spelling-to-sound translation rules (all the nonword were taken from Experiment 2 of Ferrand, 2000). The nonwords were also evaluated by asking 10 judges to read them aloud. Any alternative pronunciation was considered as an error. For an item to be selected as a legal nonword, nine of the judges must have pronounced it as following standard French spelling-to-sound translation rules. This was done in order to be able to compare nonword processing in both tasks, naming and lexical decision. All nonword stimuli were matched for number of letters ($n = 8$), number of phonemes ($n = 6$–7), number of orthographic neighbors ($n = 1$; it corresponds to the base word from which the nonword was derived from), initial phoneme and initial syllable. For the naming task, the design included two factors: lexicality (high-frequency words, low-frequency words and nonwords) and number of syllables (two or three). As can be seen in Table 3, words were matched for a number of variables: bigram frequency, number of letters, number of phonemes, and number of orthographic neighbors. Word frequencies were estimated according to a French frequency count described in Content, Mousty, and Radeau (1990). Words in the four groups were also matched for initial phoneme and initial syllable (it was also the case for nonwords). A complete list of the stimuli is presented in Appendix A.

2.1.3. Procedure

The stimuli were displayed in lowercase letters in the center of a video monitor connected to a computer. In the lexical decision and naming tasks the stimuli were presented in isolation on the center of the display screen of a Pentium computer.

Table 3
Stimulus characteristics of words used in Experiments 1 (naming) and 2 (lexical decision)

Word type	Letters	Neighbors	Frequency		Range	Phonemes		Bigram frequency	
			M	SD		M	SD	M	SD
High-frequency words									
Two syllables	8	0	34.1	21	11.5–90.7	5.7	0.55	2.82	0.27
Three syllables	8	0	34.7	23	10.3–103.8	6.6	0.67	2.84	0.12
Low-frequency words									
Two syllables	8	0	2.94	2.8	0.08–7.87	5.6	0.69	2.76	0.27
Three syllables	8	0	2.33	2.5	0.1–7.95	6.6	0.58	2.74	0.22

The stimuli remained on the screen until subjects responded either by pressing one of two response keys (word/nonword) or by reading aloud the stimulus. Reaction times, measured from stimulus onset until subjects' response, were accurate to the nearest milliseconds. The experiments were run using DMDX (Forster & Forster, in press). The inter-trial interval was 2 s. Stimulus presentation was randomized, with a different order for each subject.

3. Results

The mean naming times and percentage of errors in the naming task, and mean lexical decision latencies and percentage of errors in the lexical decision task are presented in Table 4. The latencies were trimmed applying a 1200-ms cutoff (less than 1% and 3% of the data rejected for the naming task and the lexical decision task, respectively). The data of the two tasks were submitted to separate analyses of variance. For the lexical decision task, we analyzed separately positive reaction times (words) from negative reaction times (nonwords). F values are reported by subjects ($F1$) and by items ($F2$).

Table 4
Mean response times (in milliseconds), standard deviations, and percentage of errors in Experiment 1 (naming) and 2 (lexical decision)

	High-frequency words			Low-frequency words			Nonwords		
	M	SD	%ER	M	SD	%ER	M	SD	%ER
Naming									
Two syllables	592	104	1.0	606	79	2.0	623	84	3.0
Three syllables	590	84	1.0	632	87	3.0	660	111	3.5
Difference	−2		0	+26		+1	+37		+0.5
Lexical decision									
Two syllables	628	86	2.3	686	93	7.7	830	214	10.3
Three syllables	627	92	1.1	707	105	11.3	835	213	11.7
Difference	−1		−1.2	+21		+3.6	+5		+1.4

3.1. Naming

There were two factors in the analyses of variance, lexicality (high-frequency words, low-frequency words and nonwords) and number of syllables (two vs. three). There was a main effect of lexicality: the subjects took longer to name nonwords (641.5 ms) than low-frequency words (619 ms) than high-frequency words (591 ms) [$F1(2,30) = 21.95$, $p < 0.001$; $F2(2,114) = 5.39$, $p < 0.01$]. There was also a main effect of number of syllables, with the subjects naming items with two syllables (607 ms) more quickly than those with three syllables (627.5 ms) [$F1(1,15) = 9.75$, $p < 0.01$; $F2(1,114) = 13.33$, $p < 0.01$]. More interestingly, the interaction between lexicality and number of syllables was also significant [$F1(2,30) = 5.42$, $p < 0.01$; $F2(2,114) = 3.81$, $p < 0.05$]. Planned comparisons show that the syllabic effect was significant for nonwords [$F1(1,15) = 13.77$, $p < 0.01$; $F2(1,38) = 11.67$, $p < 0.01$] and for low-frequency words [$F1(1,15) = 31.30$, $p < 0.01$; $F2(1,38) = 8.40$, $p < 0.01$] but not for high-frequency words [$F1(1,15) < 1$; $F2(1,38) < 1$]. In the error data, there were no main or interaction effects [all Fs < 1].

3.2. Additional analyses

Because some of our stimuli were morphologically complex words, naming times might be influenced not just by surface frequency of the word itself but also by the frequency of all the inflected variations of it. In order to check this possibility, we ran post hoc analyses contrasting monomorphemic words (six in each condition out of 20 per condition) and polymorphemic words (10 in each condition out of 20; nonwords were not included in these analyses). These post hoc analyses showed the same pattern of results for monomorphemic and polymorphemic words. There was a main effect of frequency for monomorphemic words [$F2(1,20) = 4.66$, $p < 0.05$] and for polymorphemic words [$F2(1,36) = 4.27$, $p < 0.05$]. There was also a main effect of number of syllables, with bisyllabic words being named faster than trisyllabic words: This was true for monomorphemic words [$F2(1,20) = 4.52$, $p < 0.05$] as well as for polymorphemic words [$F2(1,36) = 4.63$, $p < 0.05$]. The interaction between frequency and number of syllables was also significant for monomorphemic words [$F2(1,20) = 4.54$, $p < 0.05$] and polymorphemic words [$F2(1,36) = 5.38$, $p < 0.05$]. Planned comparisons show that the syllabic length effect was significant for low-frequency words only: for monomorphemic words [$F2(1,10) = 4.90$, $p < 0.05$] and for polymorphemic words [$F2(1,18) = 4.63$, $p < 0.05$].

3.3. Lexical decision

Concerning positive reaction times (for words), there was a main effect of frequency: the subjects took longer to read low-frequency words (696.5 ms) than high-frequency words (627.5 ms) [$F1(1,39) = 156.57$, $p < 0.001$ and $F2(1,76) = 37.96$, $p < 0.001$]. There was a marginally significant main effect of number of syllables (657 vs. 667 ms) [$F1(1,39) = 3.67$, $p = 0.06$; $F2(1,76) = 3.15$, $p = 0.07$]. More interestingly, the interaction between frequency and number of syllables was significant [$F1(1,39) = 4.76$, $p < 0.05$ and $F2(1,76) = 3.94$, $p < 0.05$]. Planned comparisons show that the syllabic effect was significant for low-frequency words [$F1(1,39) = 6.42$, $p < 0.02$ and $F2(1,38) = 5.13$, $p < 0.05$] but not for high-frequency words [$F1(1,39) < 1$; $F2(1,38) < 1$]. In an analysis of variance conducted on the error data, there was a main effect of frequency: Subjects made less errors for high-frequency words (1.7%) than for low-frequency words (9.5%) [$F1(1,39) = 95.47$, $p < 0.001$ and $F2(1,76) = 11.83$, $p < 0.01$]. There was no main effect of number of syllables (5% vs. 6.2%) [$F1(1,39) = 2.87$; $F2(1,76) < 1$]. However, the interaction between frequency and number of syllables was significant [$F1(1,39) = 12.94$, $p < 0.001$; $F2(1,76) = 1.04$]. Planned comparisons show that the syllabic effect was significant for low-frequency words [$F1(1,39) = 8.76$, $p < 0.01$; $F2(1,38) < 1$] but not for high-frequency words [$F1(1,39) = 3.10$; $F2(1,38) = 1.77$]. Concerning negative reaction times and percent errors for nonwords, there was no effect of number of syllables [all Fs < 1].

3.4. Additional analyses

Post hoc analyses contrasting monomorphemic words (six in each condition out of 20 per condition) and polymorphemic words (10 in each condition out of 20) were ran. These analyses showed the same pattern of results for monomorphemic and polymorphemic words. There was a main effect of frequency for monomorphemic words [$F2(1,20) = 47.9$, $p < 0.001$] and for polymorphemic words [$F2(1,36) = 7.03$, $p < 0.05$]. There was also a main effect of number of syllables, with bisyllabic words being named faster than trisyllabic words: This was true for monomorphemic words [$F2(1,20) = 6.82$, $p < 0.05$] as well as for polymorphemic words [$F2(1,36) = 4.87$, $p < 0.05$]. The interaction between frequency and number of syllables was also significant for monomorphemic words [$F2(1,20) = 4.81$, $p < 0.05$] and polymorphemic words [$F2(1,36) = 5.85$, $p < 0.05$]. Planned comparisons show that the syllabic length effect was significant for low-frequency words only: for monomorphemic words [$F2(1,10) = 8.05$, $p < 0.05$] and for polymorphemic words [$F2(1,18) = 6.77$, $p < 0.05$].

4. General discussion

The results of Experiment 1 (naming) indicate an interaction between lexicality (high-frequency words, low-frequency words, nonwords) and number of syllables (two or three): more specifically, the number of syllables influenced naming latencies only for low-frequency words and nonwords, but not for high-frequency words. This replicates the results obtained in two different experiments by Ferrand (2000). It is important to note that these results are not due to differences between items in number of letters, number of phonemes, number of orthographic neighbors, bigram frequency, initial phoneme and initial syllable. [1] Furthermore, post hoc analyses revealed that the syllabic length effect was observed for both monomorphemic and polymorphemic words.

In Experiment 1, items were presented in a mixed list (33% of high-frequency words, 33% of low-frequency words, and 33% of nonwords) as opposed to the previous experiments conducted by Ferrand (2000), so that subjects could not predict whether an item would be a word or a nonword prior to its presentation. Under these conditions, use of the nonlexical route (analytic procedure) may have been maximized and use of the lexical route (global procedure) minimized, inasmuch as these are under strategic control (see Table 1). However, the present results show very similar effects of frequency and number of syllables to those obtained by Ferrand (2000) in pure lists. Therefore, it does not seem that these two procedures are under strategic control. In fact, the MTM model of polysyllabic word reading (Ans et al., 1998) clearly states that these two routes are not under strategic control, whereas the DRC model claims that they are (Coltheart et al., 2001) (see Table 1). According to the DRC model, "As more and more nonwords are encountered, the readers turn down the lexical route (because it is never providing a correct response) or turn up the nonlexical route (because it is always providing the correct response), or both" (p. 222). However, taken together, the present results and those obtained by Ferrand (2000) suggest, in line with the predictions from the MTM model, that this kind of strategic effect on naming is not found. Deemphasizing the lexical route or the nonlexical route does not modulate the size of the effects.

The results of Experiment 2 (lexical decision, testing the same stimuli as in Experiment 1) also indicate an interaction between frequency and number of syllables: the syllabic length effect was significant only for low-frequency words but not for high-frequency words. Again, this effect was observed for both monomorphemic and polymorphemic words. As concerns the nonword data ("no" responses), we did not find a syllabic length effect in the lexical decision task. This comes as no surprise because pilot work conducted in our laboratory failed to find such an effect for nonwords in the visual lexical decision task (see also Forster & Chambers, 1973).

The present results are totally in accordance with the predictions generated by the MTM model (Ans et al., 1998) of polysyllabic word and nonword reading (see Tables 1 and 2 in the Introduction). This model offers the most convincing explanation of the present results compared to the DRC model (Coltheart et al., 1993, 2001) and

[1] One reviewer suggested that because most of our bisyllabic words end with a mute "e" (16 out of 20 both for high- and low-frequency words; see Appendix A) whereas it is almost never the case for trisyllabic words (three out of 20 for high-frequency words and 0 out of 20 for low-frequency words), this absence of matching with respect to the presence or absence of a final mute "e" between bi- and trisyllabic words might explain the lack of any syllabic length effect in high-frequency words naming. Indeed, our so-called bisyllabic words might be in fact trisyllabic words at the orthographic level. However, an analysis of the phonological and orthographic syllabic structure based on the French lexical database LEXIQUE (New, Pallier, Ferrand, & Matos, 2001; see also Appendix A) revealed that our bisyllabic words are really bisyllabic either at the phonological or orthographic level. Furthermore, as showed in the Introduction (see Tables 1 and 2), none of the presented models of polysyllabic word reading predicted a syllabic length effect for high-frequency words.

the PDP model (Jared & Seidenberg, 1990; Seidenberg & McClelland, 1989). The MTM model has been developed explicitly for polysyllabic word and nonword reading. In particular, this model explicitly includes a syllabic layer that makes it possible to simulate the recognition of multisyllabic words. This is important because there is now abundant empirical evidence that syllables influence the recognition/naming of words (see Ferrand & Segui, 2003, for a review). The MTM model is a feedforward distributed connectionist network that contains four layers of processing units: two orthographic input layers, a phonological output layer, and an intermediate episodic memory layer. The phonological layer has three types of units: phonemes, syllables and syllabic constituents (onset and time). In this model, the mapping from orthography to phonology emerges from the integrated activation of previously whole words and word syllabic segments. Furthermore, it postulates the existence of two reading procedures, a global procedure using knowledge about whole word correspondences, and an analytic procedure based on the activation of word syllabic segments. However, these two procedures do not work in parallel: Global processing always proceeds first, the analytic procedure applying only secondarily when global processing has failed. Since the global procedure always proceeds first, the analytic procedure being used only after global processing has failed, the MTM model predicts that naming latencies of all words would be systematically shorter than the naming latencies of any nonwords. More specifically, an increase in naming latencies with syllabic length is predicted for nonwords and very low-frequency words since they are processed analytically, and this is exactly what we obtained in Experiment 1 (see also Ferrand, 2000).

Concerning visual word recognition, the MTM model also predicts an increase in response latencies with syllabic length for very low-frequency words (but not for high-frequency words) since they are likely to be processed analytically. However, it predicts an absence of syllabic effects for nonwords, simply because this model assumes that lexical decision for nonwords is performed without any involvement of the analytic procedure.

In its present form (see Tables 1 and 2), the DRC model of visual word recognition and naming (Coltheart, 1978; Coltheart et al., 1993, 2001) cannot explain the syllabic length effects obtained in the present experiments. As Jackson and Coltheart (2001) put it, "At present, the DRC model deals only with monosyllabic words, because it is currently unknown how GPC works for polysyllabic words [...]" (p. 54). However, a modified version of the model replacing graphemes–phonemes by syllables could in principle explain these results in both naming and lexical decision. Traditional dual-route theory (Coltheart, 1978) assumes that normal readers have two methods at their disposal for converting print into speech: a lexical route and a nonlexical route. For the lexical route, words are represented in an orthographic input lexicon and are read aloud by retrieving the word's pronunciation. The nonlexical route converts the graphemic representation of a letter string into phonemes piece by piece. In other words, the lexical route processes letter strings in parallel, whereas the nonlexical route processes letter strings sequentially. The grapheme–phoneme conversion approach may have been motivated by properties of the English language. In English, syllabification of words is quite complex, while the resulting syllables show little consistency with respect to their phonological interpretation. Therefore, this theory has chosen to bypass the explicit use of syllables, and assumes that groups of graphemes from the visual input trigger conversion rules (Coltheart, 1978). However, if we consider English words with clear syllable boundaries (such as DIVORCE) or French words (i.e. French is usually described as syllable-timed language having clear syllable boundaries), and if we replace phonemes with syllables when polysyllabic word naming is considered, then the dual-route model could easily explain the syllabic length effect. This modified version of the dual-route model in which the nonlexical route would operate at the syllabic level rather than at the phoneme level, offers a potential explanation of the present results. In this modified model, syllabic length effects on naming latency would reflect the serial operation of the nonlexical route. Because the lexical route processes high-frequency words so quickly, the nonlexical route makes no contribution to the naming of these words. When the stimulus is a very low-frequency word, however, lexical processing is sufficiently slow to allow a substantial contribution from the nonlexical route. When the stimulus is a nonword, the nonlexical route is the major determinant of pronunciation, since nonwords cannot be pronounced correctly via the lexical route. It follows that the syllabic length effect should be nonexistent for high-frequency words, but strong for very low-frequency words, and even stronger for nonwords. This is exactly the pattern of results we obtained. Therefore, a modified version of the dual-route model which incorporates syllabic units instead of phonemic units would offer a coherent explanation of the present results.

Having said that, it is not sure that Max Coltheart is ready to accept the insertion of syllabic units in DRC. In his seminal work, Coltheart (1978) examined this possibility and wrote that "some theoretical advantage might be gained by supposing that the units used during the process of converting a printed to a phonological representation are syllables, rather than phonemes" (p. 161). However, he rejected this possibility on the basis that this approach is "difficult to reconcile with our ability to pronounce nonwords, with the symptoms of surface dyslexia, and with differences observed between subjects' responses to regular and exception words, whereas the approach based on GPCs deals with all three of these" (p. 168). There is also an aspect of the results that this modified version of the model cannot explain. It is the fact that syllabic length effects are not affected by the strategic use of the two routes. As shown in Tables 1 and 2, the DRC model clearly states that readers can strategically adjust the relative strength of the two routes. According to the model, if the reader is sure that no nonwords are to be presented (pure list case), but there will be only words, then it would pay the reader to turn down the nonlexical route. If the reader knows in advance that no words are to be presented, but there will be only nonwords, then it would pay the reader to turn down the lexical route. It predicts a strong syllabic effect for pure lists (in which words and nonwords are presented separately, as was done in Ferrand, 2000) and a weaker (or no) effect in mixed lists (in which words and nonwords are presented together, as was done in the present experiments). However, our results show no difference in size of syllabic effects for mixed and pure lists.

Overall, our results suggest that reading involves a global and parallel procedure for common words and an analytic and sequential procedure for low-frequency words (in both naming and visual recognition) and for nonwords (in naming only), and that the syllable constitutes an important unit of reading in French.

Appendix A

Grammatical category, word frequency, segmental structure and syllabification

Word	GC	Frequency	Segmental structure[a]	Segmental syllabification[a]
High-frequency two-syllables				
Bataille	Noun	90.7	CVCVY	CV-CVY
Commande	Noun	13.6	CVCVC	CV-CVC
Conclure	Verb	50.3	CVCCVC	CV-CCVC
Concours	Noun	30.2	CVCVC	CV-CVC
Complice	Noun	21.8	CVCCVC	CV-CCVC
Farouche	Adjective	21.4	CVCVC	CV-CVC
Formelle	Adjective	23.9	CVCCVC	CVC-CVC
Mâchoire	Noun	18.1	CVCYVC	CV-CYVC
Patronne	Noun	15.3	CVCCVC	CV-CCVC
Parlante	Adjective	53.4	CVCCVC	CVC-CVC
Précieux	Adjective	35.1	CCVCYV	CCV-CYV
Pression	Noun	34.1	CCVCYV	CCV-CYV
Prochain	Noun	71.4	CCVCV	CCV-CV
Prophète	Noun	20.0	CCVCVC	CCV-CVC
Radieuse	Adjective	11.5	CVCYVC	CV-CYVC
Réplique	Noun	14.1	CVCCVC	CV-CCVC
Reproche	Noun	46.1	CVCCVC	CV-CCVC
Richesse	Noun	50.8	CVCVC	CV-CVC
Supplice	Noun	16.9	CVCCVC	CV-CCVC
Surprise	Noun	42.2	CVCCCVC	CVC-CCVC
High-frequency three-syllables				
Balancer	Verb	22.0	CVCVCV	CV-CV-CV
Colonial	Noun	13.2	CVCVCYVC	CV-CV-CYCV
Composer	Verb	59.2	CVCVCV	CV-CV-CV
Comparer	Verb	31.6	CVCVCV	CV-CV-CV
Consacré	Adjective	22.8	CVCVCCV	CV-CV-CCV
Fatiguer	Verb	23.8	CVCVCV	CV-CV-CV
Formuler	Verb	15.9	CVCCVCV	CVC-CV-CV
Maritime	Adjective	10.3	CVCVCVC	CV-CV-CVC
Passager	Noun	20.8	CVCVCV	CV-CV-CV
Partager	Verb	45.9	CVCCVCV	CVC-CV-CV
Préciser	Verb	34.9	CCVCVCV	CCV-CV-CV

Préparer	Verb	103.8	CCVCVCV	CCV-CV-CV
Protéger	Verb	38.0	CCVCVCV	CCV-CV-CV
Procurer	Verb	27.2	CCVCVCV	CCV-CV-CV
Ramasser	Verb	35.7	CVCVCV	CV-CV-CV
Résonner	Verb	12.8	CVCVCV	CV-CV-CV
Retomber	Verb	51.2	CVCVCV	CV-CV-CV
Ridicule	Noun	75.6	CVCVCVC	CV-CV-CVC
Susciter	Verb	29.0	CVCVCV	CV-CV-CV
Survivre	Verb	20.6	CVCCVCCV	CVC-CV-CVC
Low-frequency two-syllables				
Barrette	Noun	0.34	CVCVC	CV-CVC
Copieuse	Adjective	2.68	CVCYVC	CV-CYVC
Conjoint	Noun	2.55	CVCYV	CV-CYV
Consonne	Noun	1.78	CVCVC	CV-CVC
Comptant	Noun	6.08	CVCV	CV-CV
Fabrique	Noun	7.87	CVCCVC	CV-CCVC
Fortuite	Adjective	6.89	CVCCYVC	CVC-CYVC
Marraine	Noun	2.38	CVCVC	CV-CVC
Passoire	Noun	0.51	CVCYVC	CV-CYVC
Parterre	Noun	4.84	CVCCVC	CVC-CVC
Prémices	Noun	0.80	CCVCVC	CCV-CVC
Pressing	Noun	0.12	CCVCVC	CCV-CVC
Prodigue	Adjective	7.27	CCVCVC	CCV-CVC
Prothèse	Noun	0.08	CCVCVC	CCV-CVC
Rallonge	Noun	0.93	CVCVC	CV-CVC
Réglisse	Noun	0.72	CVCCVC	CV-CCVC
Retouche	Noun	4.04	CVCVC	CV-CVC
Ripaille	Noun	0.55	CVCVY	CV-CVY
Suffrage	Noun	7.48	CVCCVC	CV-CCVC
Surplomb	Noun	0.08	CVCCCV	CVC-CCV
Low-frequency three-syllables				
Barillet	Noun	0.29	CVCVYV	CV-CV-YV
Communal	Adjective	3.36	CVCVCVC	CV-CV-CVC
Concerto	Noun	2.08	CVCVCCV	CV-CVC-CV
Confetti	Noun	1.10	CVCVCV	CV-CV-CV
Conjurer	Verb	7.40	CVCVCV	CV-CV-CV
Fabuleux	Adjective	7.95	CVCVCV	CV-CV-CV
Forgeron	Noun	4.16	CVCCVCV	CVC-CV-CV
Marabout	Noun	1.19	CVCVCV	CV-CV-CV
Patineur	Noun	0.63	CVCVCVC	CV-CV-CVC
Parfumer	Verb	2.42	CVCCVCV	CVC-CV-CV
Prédicat	Noun	2.25	CCVCVCV	CCV-CV-CV
Préfacer	Verb	0.10	CCVCVCV	CCV-CV-CV

Profaner	Verb	1.61	CCVCVCV	CCV-CV-CV
Prohiber	Verb	0.21	CCVVCV	CCV-V-CV
Ratisser	Verb	0.80	CVCVCV	CV-CV-CV
Résident	Noun	1.10	CVCVCV	CV-CV-CV
Repriser	Verb	1.06	CVCCVCV	CV-CCV-CV
Ricaneur	Noun	0.38	CVCVCVC	CV-CV-CVC
Superflu	Noun	7.74	CVCVCCCV	CV-CVC-CCV
Surmener	Verb	0.59	CVCCVCV	CVC-CV-CV

Note: GC, grammatical category; Frequency, in occurrences per million; C, consonant; V, vowel; Y, semivowel.
[a] Taken from New et al. (2001).

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