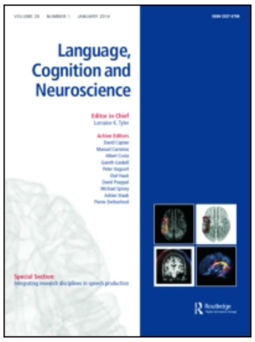

Language and Cognitive Processes

ISSN: 0169-0965 (Print) 1464-0732 (Online) Journal homepage: https://www.tandfonline.com/loi/plcp20

Replicating syllable frequency effects in Spanish in German: One more challenge to computational models of visual word recognition

Markus Conrad & Arthur Jacobs

To cite this article: Markus Conrad & Arthur Jacobs (2004) Replicating syllable frequency effects in Spanish in German: One more challenge to computational models of visual word recognition, Language and Cognitive Processes, 19:3, 369-390, DOI: 10.1080/01690960344000224

To link to this article: https://doi.org/10.1080/01690960344000224

Published online: 03 Jun 2010.

Submit your article to this journal

Article views: 170

View related articles

Citing articles: 7 View citing articles

Full Terms & Conditions of access and use can be found at
https://www.tandfonline.com/action/journalInformation?journalCode=plcp21

LANGUAGE AND COGNITIVE PROCESSES, 2004, *19* (3), 369–390

Replicating syllable frequency effects in Spanish in German: One more challenge to computational models of visual word recognition

Markus Conrad and Arthur M. Jacobs
Catholic University of Eichstaett-Ingolstadt, Eichstaett, Germany

Two experiments tested the role of syllable frequency in word recognition, recently suggested in Spanish, in another shallow orthography, German. Like in Spanish, word recognition performance was inhibited in a lexical decision and a perceptual identification task when the first syllable of a word was of high frequency. Given this replication of the inhibitory effect of syllable frequency in a second language, we discuss the issue whether and how computational models of word recognition would have to represent a word's syllabic structure in order to accurately describe processing of polysyllabic words.

Several results from recent work on word recognition in Spanish suggest that "any model of lexical access has to incorporate a syllabic level of representations or include the syllable as a sublexical unit of processing in Spanish" (Álvarez, Carreiras, & de Vega, 2000; Álvarez, Carreiras, & Taft, 2001; Álvarez, de Vega, & Carreiras, 1998; Carreiras, Álvarez, & de Vega, 1993; Carreiras & Perea, 2002; Dominguez, de Vega, & Cuetos, 1997; Perea & Carreiras, 1995, 1996, 1998). As noted by these authors, this conclusion might be generalisable to other Romance languages with well-defined syllable boundaries, such as Italian, but not to English. In English, lexical access based on syllables might not be functional, because of its relatively high inconsistency (Ziegler, Stone, & Jacobs, 1997) and its relatively ill-defined syllable boundaries (Álvarez et al., 2001).

Correspondence should be addressed to Arthur M. Jacobs, Department of Psychology, Catholic University Eichstaett-Ingolstadt, Ostenstr. 26, D-85072 Eichstaett, Germany. Email: ajacobs@zedat.fu-berlin.de.

This research was supported by two grants of the Deutsche Forschungsgemeinschaft (DFG-Forschergruppe: "Dynamik kognitiver Repräsentationen", TP 7/Jacobs "Zur Rolle phonologischer Prozesse beim Lesen", TP 8/Jacobs,Gauggel "Zur Rolle des visuellen Wortformsystems beim Lesen"; Philipps-University Marburg).

© 2004 Psychology Press Ltd

http://www.tandf.co.uk/journals/pp/01690965.html DOI: 10.1080/01690960344000224

Whereas there is longstanding evidence for the role of syllabic structure in the perception and production of speech in several languages (e.g., Carreiras & Perea, in press; Ferrand, Seguí, & Humphreys, 1997; Morais, Content, Cary, Mehler, & Seguí, 1989; Sebastián-Gallés, Dupoux, Seguí, & Mehler, 1992), the detection of an inhibitory effect of the positional frequency of the first syllable[1] in tasks in which no overt perception or production of speech is needed is a recent discovery, limited to the Spanish language. This is theoretically challenging, because no computational account of this effect has yet been offered. In a lexical decision task response times to bisyllabic Spanish words were longer when their first syllable was of high positional frequency than when it was of low frequency (Perea & Carreiras, 1998). This inhibitory effect of syllable frequency was more pronounced for low-frequency words. While Perea and Carreiras (1995) reported a similar pattern of results for a perceptual identification task, more recently Álvarez et al. (2001) could show that this inhibitory effect of syllable frequency is not confounded with the possible influence of another sublexical structure, the basic orthographic syllable structure or BOSS (Taft, 1979).

Frequencies of morphologically defined sublexical units like stems that are often highly positively correlated with the frequency of a word's first syllable, seem to facilitate lexical access (de Jong, Schreuder, & Baayen, 2000). Therefore, the pattern of results reported by Perea and Carreiras (1998) is likely to be related only to the phonologically defined syllabic structure of words. However, in contrast to perceptual identification and lexical decision tasks, the naming task has been shown to produce a facilitatory effect of the frequency of the first syllable in Spanish (Perea & Carreiras, 1996, 1998).

How can models of visual word recognition account for these findings suggesting a functional role of syllabic structure? As a matter of fact, none of the currently used computational models of word recognition (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; Grainger & Jacobs, 1996; Jacobs, Graf, & Kinder, 2003; Ziegler, Perry, & Coltheart, 2000; Zorzi, Houghton, Butterworth, 1998) has yet been shown to (re)produce an inhibitory syllable frequency effect. The simple reason is that all of these models exclusively deal with the processing of monosyllabic words (see Ans, Carbonnel, & Valdois, 1998, for a model of naming polysyllabic words). As far as monosyllabic words are concerned, the general pattern of results is that when sublexical units are of high frequency, then word recognition performance is facilitated compared with when words have

[1] The positional frequency of a syllable can be understood as the number of words that share a given syllable in the same position (e.g., first or second syllable of the word) or as the cumulated word frequency of those words.

sublexical units of low frequency. Examples are bigram frequency (Massaro & Cohen, 1994; but see Paap & Johansen, 1994), positional letter frequency (Grainger & Jacobs, 1993), trigram frequency (Seidenberg, 1987), or subcomponent frequency (Nuerk, Rey, Graf, & Jacobs, 2000).

Basically, the above-mentioned computational models account for such facilitatory effects of the frequency of sublexical units by assuming that either sublexical or lexical processing units (or connections between units) are frequency-sensitive, higher levels of frequency being correlated with either lower activation thresholds or higher resting activation levels. To account for inhibitory effects of the frequency of words or their parts, current localist connectionist models such as the Multiple Read-Out Model (MROM; Grainger & Jacobs, 1996; Jacobs et al., 2003) or the revised dual-route cascaded model (DRC; Coltheart et al., 2001) make use of the inhibitory connections between lexical units. However, to be able to deal with inhibitory effects of sublexical units, such as syllables, these models presumably must be revised by including a new level of representation, namely syllabic units. This is the approach taken by Carreiras et al. (1993), Carreiras and Perea (2002), Perea and Carreiras (1998), or Álvarez et al. (1998, 2000, 2001) who interpret their results in the light of a prequantitative (verbal) version of an interactive activation model (see General Discussion).

In the present study we asked whether the inhibitory effects of syllable frequency reported for the Spanish language could be generalised to a non-Romance language having a shallow orthography, German. If so, the case for a new round of revision in current computational models of word recognition would be strengthened and theoreticians would have to consider the question of including syllabic units into their models or other structures able to account for such a general effect.

Although both Spanish and German have a shallow orthography, the assumption that German readers might rely in the same way on the syllabic structure of words as Spanish readers apparently do, is not obvious. Syllables in Spanish tend to be relatively short, about 70% of all existing syllables following a simple CV (consonant-vocal) – or CVC-structure. Altogether, there are approximately 3250 Spanish syllables (Carreiras & Perea, 2003; Dominguez et al., 1997). This is not the case in German where one syllable in the extreme case can be up to 10 letters long (as in the word SCHRUMPFST, meaning ‘you shrink’). Moreover, there are about three times more syllables in German than in Spanish and less than 30% of the approximately 6000 German syllables belong to the CV or CVC class. Thus, a hypothetical mental syllabary in German would be both bigger and less consistent than its Spanish counterpart. Third, German linguists still debate about the clarity of syllabic boundaries, given that written and spoken syllables are often not identical. ''While the number of syllables (of a German word) is usually obvious, the precise position of the syllable break is much harder to determine'' (Wiese, 1996). Finally, there is ample evidence that German readers use subsyllabic units (graphemes and phonemes) when processing monosyllabic words (Nuerk et al., 2000; Wimmer & Goswami, 1994; Ziegler, Perry, Jacobs, & Braun, 2001; see Rey, Ziegler, & Jacobs, 2000, for compatible findings in English and French). Thus one might doubt that it is an efficient strategy for German readers to automatically retrieve syllable information from a hypothetical store containing about 6000 entries of very diverse length and structure when reading a word.

In other words, a syllable frequency effect might be special to word processing in Spanish or similar Romance languages, because of the high simplicity and clearness of syllabic structure in this language. On the other hand, if effects of syllable frequency also show up in experiments using the German language, this would support the hypothesis that effects observed in experiments using monosyllabic words cannot simply be generalised to the processing of polysyllabic words and strengthen the need for a revision of current computational models of visual word recognition.

EXPERIMENT 1: LEXICAL DECISION

Experiments that examined the effects of syllabic structure in Spanish consistently revealed an inhibitory effect of syllable frequency – at least as concerns the first syllable of bisyllabic words – when a lexical decision was required. In the first of these studies, the latencies of responses to bisyllabic words were found to be longer when the average of the positional frequency of both their syllables was high (Carreiras et al., 1993). In subsequent research the operationalisation of syllable frequency was restricted to the positional frequency of the first syllable (Perea & Carreiras, 1995, 1996, 1998). Again, in a lexical decision task Perea and Carreiras (1998, Experiment 1) reported an inhibitory effect of syllable frequency that was more pronounced for low-frequency words. For high-frequency words, there was no significant effect of syllable frequency. In a regression analysis of their data Perea and Carreiras (1998) could show that the number of higher-frequency syllabic neighbours was strongly related to the inhibitory effect of syllable frequency. Also, the number of higher-frequency syllabic neighbours itself, manipulated as an independent variable, produced an inhibitory effect (Perea & Carreiras, 1998, Experiment 3).

Because in the study of Perea and Carreiras (1998) the syllable of interest was the first, other studies focused on the role of subsequent syllables. Interestingly, when the positional frequency of a word's second syllable was manipulated, this yielded a facilitatory tendency (Álvarez et al., 2000, Experiment 3). However, these authors also reported an inhibitory effect of the frequency of the second syllable for pseudowords. In pseudowords that were composed of two syllables, each of them of either high or low frequency, the frequency of both syllables caused an inhibitory effect. In contrast, when the stimulus was a word, especially a word with a first syllable of low frequency, response times tended to be shorter when the frequency of the second syllable was high. To interpret these findings, Álvarez et al. (2000) chose a sort of serial (activation-selection) processing account: polysyllabic word representations are activated via their first syllable whereas the second syllable is important for the selection of the correct candidate amongst this activated set or cohort. As concerns pseudowords, a correct candidate cannot be found because they are not listed in the mental lexicon. Therefore, the frequency of the second syllable may prolong the selection process because more candidates could be generated depending on their similarity to the second syllable of the pseudoword. Concerning the role of subsequent syllables more empirical support for the assumption of serial processing was found by Álvarez et al. (1998) who manipulated the frequency of trisyllabic words and pseudowords. They reported significant facilitatory effects of the frequency of the second and the third syllable of words in a lexical decision task, whereas in pseudowords syllable frequency effects of an inhibitory nature were found for all three syllables.

Method

Participants. Twenty-nine students from the Catholic University of Eichstaett-Ingolstadt participated in the experiment. Their participation was rewarded with course credits. All were native speakers of German and had normal or corrected-to-normal vision.

Design and stimuli. A set of 112 bisyllabic German words of five and six letters in length were selected from the CELEX-database (Baayen, Piepenbrock, & van Rijn, 1993) according to the orthogonal combination of two factors in a within-participant 2×2 design: word frequency and positional frequency of the first syllable. Syllable frequency was defined as token frequency and computed by cumulating the frequencies of all words that contain a given syllable in the first position. A word was considered of high frequency when its cited frequency of occurrence in the CELEX-Database was greater or equal to 100/million, and of low frequency when the same measure did not pass 10/million. A syllable was considered of low frequency when it had a maximum token positional frequency of occurrence of 800/million. The minimum value for a high frequency syllable was set at 2600/million. Words were matched across the four experimental conditions for length, number of orthographic neighbours and positional frequency of the second syllable. None of the words had orthographic neighbours of higher word frequency. The items used in the word conditions are listed in the Appendix. Characteristics for words in Experiment 1 are shown in Table 1. In addition, 112 nonwords were constructed combining two strings of letters (each two or three letters long) that exist as the first or second syllable of a real word. The syllables used for these nonwords belonged to the extreme ranges of syllable frequency. Controlling for the number of possible orthographic neighbours and length (all nonwords were five or six letters long), nonwords were organised in four groups, forming a 2 × 2 design according to the orthogonal combination of the factors positional frequency of the first and positional frequency of the second syllable.

Apparatus and Procedure. Stimuli were presented in uppercase letters using Courier 24 type font on a 17″ ProNitron colour monitor (resolution 1024 × 768 pixel, 75 Hz) driven by an Umax Pulsar computer. Stimulus presentation and response recording was controlled by PsyScope software (V. 1.2.4 PPC; Cohen & MacWhinney, 1993). At the utilised viewing distance of 50 cm the stimuli subtended a visual angle of approximately 1.7 degrees. Each trial was initiated by a fixation point appearing at the centre of the screen for 500 ms. The fixation point was then replaced by a blank screen (0 ms), followed by the word or nonword stimulus that remained visible until participants pressed a button indicating their decision concerning the lexicality ('yes'-button for a word; 'no'-button for a

TABLE 1
Characteristics of words used in Experiment 1. Means (M) and ranges of the independent variables word frequency (WF) and frequency of the first syllable (SF1). Means and ranges of variables that were held constant: frequency of the second syllable (SF2), density of orthographic neighbourhood (N) and mean word length (L)

	WF		*SF1*		*SF2*		*N*		*L*
Word class	*M*	*Range*	*M*	*Range*	*M*	*Range*	*M*	*Range*	*M*
High WF High SF	185	101–373	12711	3333–21,921	810	108–4742	1.14	0–5	5.71
High WF Low SF	176	110–480	353	125–786	1075	131–3400	1.25	0–4	5.68
Low WF High SF	3.13	0.17–9	15610	2642–110,013	1193	1–16,350	1.07	0–6	5.71
Low WF Low SF	3.46	0–8.17	176	2–573	450	3–789	1.04	0–6	5.71

nonword) of the stimulus. The time between the onset of stimulus presentation and the response was measured as the dependent variable. There were also ten initial training trials. Participants were tested individually in a quiet room.

Results and Discussion

Mean response latencies and error rates for words and nonwords in Experiment 1 are shown in Table 2.

Words. Mean correct response latencies and error percentages (see Table 2) were submitted to separate analyses of variance (ANOVAs) by participants and by items (F_1 and F_2, respectively). Concerning response times, the analyses revealed significant main effects of both word frequency and syllable frequency. High-frequency words were responded to 170 ms faster than low-frequency words, $F_1(1, 28) = 158.30$, $p \leq .0001$; $F_2(1, 108) = 57.09$, $p \leq .0001$, whereas the frequency of a word's first syllable caused a delay of 120 ms in the latencies, $F_1(1, 28) = 39.50$, $p \leq .0001$; $F_2(1, 108) = 28.82$, $p \leq .0001$. The interaction between word frequency and syllable frequency was also significant, $F_1(1, 28) = 20.09$, $p \leq .0001$; $F_2(1, 108) = 9.98$, $p \leq .002$, the inhibitory effect of syllable frequency being stronger for low-frequency words (191 ms), than for high-frequency words (49 ms). Still, also for high-frequency words only, the inhibitory

TABLE 2
Mean reaction times (RT; in ms), standard deviation (SD) of reaction times (ms) and percentage of errors for words and nonwords in Experiment 1

Words	*Word frequency*					
	High			*Low*		
Syllable frequency	*RT*	*SD*	*% error*	*RT*	*SD*	*% error*
High	671	104	4.7	911	166	25.6
Low	622	71	0.9	720	112	11.1
Nonwords	*SF1*					
	High			*Low*		
SF2	*RT*	*SD*	*% error*	*RT*	*SD*	*% error*
High	833	86	3.3	825	169	2.73
Low	846	140	3.6	796	107	1.9

Note: SF1 and SF2 = Frequency of the first and the second syllable respectively of nonwords.

effect of syllable frequency remained statistically significant, $F_1(1, 28) = 18.94$, $p \leq .0002$; $F_2(1, 54) = 4.33$, $p \leq .05$.

The error data mirrored this pattern of results, showing a facilitatory effect of word frequency with 2.7% errors for high-frequency words vs. 18.4% for low-frequency words, $F_1(1, 28) = 99.29$, $p \leq .0001$; $F_2(1, 108) = 30.59$, $p \leq .0001$, and an inhibitory effect of syllable frequency with 15.2% errors vs. 5.9% for high vs. low syllable frequency, respectively, $F_1(1, 28) = 94.01$, $p \leq .0001$; $F_2(1, 108) = 26.09$, $p \leq .0001$. The interaction between the two factors also reached statistical significance, high syllable frequency provoking more errors in low-frequency words than in high-frequency words, $F_1(1, 28) = 84.87$, $p \leq .0001$; $F_2(1, 108) = 12.02$, $p \leq .0008$.

Considering the fact that the error rates for words, especially for the condition with low-frequency words and high-frequency syllables, are relatively high, we conducted some further analyses of variance in order to verify if the inhibitory effects of syllable frequency would hold when error-prone words are excluded. We set a maximum error rate of 30% as a criterion for words to enter in these analyses. Ten words amongst the 112 stimuli were excluded from the analyses. All effects of syllable frequency remained statistically significant. The frequency of the first syllable now caused a delay of 78 ms in the latencies, $F_1(1, 28) = 39.47$, $p = \leq .0001$; $F_2(1, 98) = 19.34$, $p \leq .0001$. The interaction between the factors syllable frequency and word frequency remained statistically significant, $F_1(1, 28) = 11.94$, $p \leq .002$; $F_2(1, 98) = 5.48$, $p \leq .03$.

Error rates still were increased for words with high-frequency syllables with 8.8% errors vs. 2.4% for high vs. low syllable frequency, respectively, $F_1(1, 28) = 31.42$, $p \leq .0001$; $F_2(1, 98) = 38.44$, $p \leq .0001$. The interaction between the factors syllable frequency and word frequency remained statistically significant, $F_1(1, 28) = 18.34$, $p \leq .0002$; $F_2(1, 98) = 14.59$, $p \leq .0002$).

In sum, all effects reported as results of the analyses based on all 112 stimuli remained statistically significant after the exclusion criterion had been applied so that they cannot be attributed to the specific contribution of error-prone words.

Nonwords. As concerns response times to nonwords there was one significant main effect, an inhibition due to the frequency of the first syllable, yet only in the participants' analysis, $F_1(1, 28) = 5.93$, $p \leq .03$. Nonwords with a low-frequency first syllable were responded to 29 ms faster than when the first syllable was of high frequency. The frequency of the second syllable did not produce a significant main effect. But the interaction between first and second syllable frequency was significant in the participants' analysis, $F_1(1, 28) = 4.68$, $p \leq .04$. The tendency for second syllable frequency was facilitatory when first syllable frequency was high, but inhibitory for low first syllable frequency. In one of the four conditions, response latencies were shorter than in the three others: Nonwords that had two syllables of low frequency were responded to 38 ms faster than the other nonwords, $F_1(1, 28) = 14.07$, $p \leq .0008$.

In the error data, a significant inhibitory effect of first syllable frequency emerged, $F_1(1, 28) = 8.32$, $p \leq .01$, with 3.5% errors for high first syllable frequency vs. 2.4% for low. No main effect for second syllable frequency was obtained, but a significant interaction between first and second syllable frequency, $F_1(1, 28) = 4.68$, $p \leq .04$, with high frequency of the second syllable provoking more errors when the frequency of the first syllable was low, as well as a significant effect when nonwords that contained no syllable of high frequency were compared with those in which at least one syllable was of high frequency, $F_1(1, 28) = 10.07$, $p \leq .004$, with 3.6% errors for nonwords with at least one syllable of high frequency vs. 1.9% for completely low syllable frequency nonwords.

The important finding of Experiment 1 is that the frequency of the first syllable clearly inhibited the processing of bisyllabic German words. This inhibition appeared not only in a significant effect on response times, but also in increased error rates for words with high-frequency first syllables. Although the inhibitory effect was more pronounced for words of low frequency, it was also significant for high-frequency words, both in the F_1 and F_2 analysis. This is a notable difference as compared with the results reported for the Spanish language: there, the syllable frequency effect was significant only in the F_1 analysis and not for high-frequency words (e.g., Perea & Carreiras, 1998).

Perhaps this difference with regard to the Spanish studies is due to the way syllable frequency was calculated in our study. Whereas Álvarez et al. (2001) had used a type measure, we used the token frequency of a syllable as an independent variable. Álvarez et al. (2001) argued that a type measure (the number of words that share a given syllable in identical position) should be a more adequate way to calculate syllable frequency than a token measure (calculated as the summed frequency of all words sharing a syllable in the same position), because the type measure directly refers to the number of syllabic neighbours of a word which are supposed to be responsible for the delay in the processing of polysyllabic words (Álvarez et al., 1998, 2000, 2001; Carreiras et al., 1993; Perea & Carreiras, 1998).

Yet, in German this argument may fail. While in all Romance languages a relation between two nouns or between a verb and a noun is expressed most of the time by the use of prepositions (e.g., *the captain of the ship*), in German two words are most often simply combined to compounds (e.g., Schiffskapitän). The possible dimensions of these German compounds are enormous: they often include four normally independent single words and more than 15 letters. Thus a frequent syllable can be part of a great number of words that are rarely used in everyday language. Use of a token measure of syllable frequency thus assigns a stronger weight to the real frequency of occurrence of a syllable. Still, there is a notable correlation between the two different measures ($r = .58$ for all bisyllabic German words of five and six letters length), and because both of them have been shown to produce inhibitory effects, at current we see no theoretical reason for preferring one over the other.

Our nonword data are consistent with the view that the frequency of the first syllable inhibits lexical access, because the first syllable activates a set of lexical candidates (Álvarez et al., 2000). The inhibitory effect of a nonword's first syllable's frequency thus might reflect the fact that more word units are preactivated and competing for lexical selection than in the case of a nonword with a low-frequency first syllable. The activation of lexical candidates might in principle also be provoked by the second syllable as suggested by our result that second syllable frequency had an inhibitory effect when first syllable frequency was low in nonwords. However, because a main effect of second syllable frequency did not appear in the data, the first syllable seems to play a stronger role for this hypothetical activation of lexical candidates. This finding thus is compatible with the serial (activation-selection) account of Álvarez et al. (1998, 2000) on polysyllabic word processing.

Reanalysis of Experiment 1

The results of Experiment 1 seem to provide evidence for the automatic computation of syllabic codes in the processing of polysyllabic words. However, the frequencies of other sublexical components that do not rely on syllabic structure might also have been influential in the present experiment given their strong correlation with syllable frequency. For example, the frequencies of the first two or three letters of words are automatically increased when the frequency of the first syllable is high. Thus, one might argue that the inhibitory effect in Experiment 1 was not necessarily driven by syllabic structure but due to purely orthographic factors, such as the positional frequency of bigrams or trigrams at the beginning of a word. Analogously, the cohort size of some number of initial phonemes could also have played a role in our experimental effects. To strengthen the theoretical assumption that the inhibitory effect in Experiment 1 is caused by inhibition from a set of competing word representations that is activated by a word's first syllable, we thus had to check the likeliness of these alternative accounts.

For words, like those used in Experiment 1, whose first syllable contains either two or three letters, the correlation between syllable frequency and the frequency of the first two or three letters is too strong to be experimentally disentangled. Therefore, we ran a multiple regression analysis on the data of Experiment 1, using six predictors for the obtained response times: word frequency, frequency of the first syllable, positional frequency of the first bigram, positional frequency of the first trigram, cohort size of the first two phonemes and cohort size of the first three phonemes. Bigram and trigram frequency were calculated analogously to the computation of syllable frequency as the cumulated frequencies of all words containing this combination of letters at their beginning. Cohort size of the first two or three phonemes was calculated as the number of words containing the same number of phonemes and sharing the same initial two or three phonemes. This analysis showed a significant facilitatory effect of word frequency on response times, $F(1, 105) = 31.14$, $p \leq .0001$, and a significant inhibitory effect of syllable frequency, $F(1, 105) = 4.32$, $p \leq .05$. For none of the other predictors was a significant effect obtained. The only other measure than syllable frequency that at least a predictive tendency could be reported for was the frequency of the first trigram, $F(1, 105) = 2.78$, $p \leq .09$. Yet, this tendency had a facilitatory direction, so that the influence of the frequency of a word's first three letters, being positively correlated with syllable frequency, cannot be held responsible for the inhibitory effect obtained in Experiment 1. Coefficients of simple and multiple correlations between predictors and response times are given in Table 3.

In sum, the results of Experiment 1 are compatible with the results reported for the Spanish language and generalise them as far as the functional role of syllabic structure for lexical access to bisyllabic words is concerned. Although the hypothetical mental syllabary is much larger in German than in Spanish, although German syllable units are much more variable, longer and have unclearer boundaries than Spanish ones, and although the high consistency of the German orthography provides no a priori reason for using higher-level units such as syllables in reading, the

TABLE 3
Pearson product-moment (r) and partial correlations (pr) between reaction times and six predictors in Experiment 1

Predictor	*r*	*pr*
Word frequency	−.458	−.478*
Positional frequency of the first syllable	.392	.199*
Positional frequency of the first two letters	.371	.058
Positional frequency of the first three letters	.245	−.161
Cohort size of the first two phonemes	.079	−.025
Cohort size of the first	.058	.071

*$p \leq .05$.

present results lend support to the notion that information about syllables is automatically computed when processing polysyllabic written words.

Still, before drawing such a conclusion, one should attempt to demonstrate that the effect is not a mere by-product of task-specific processes, following the logic of functional overlap modelling formulated by Jacobs (1994; see also Grainger & Jacobs, 1996; Jacobs & Grainger, 1994; Jacobs, Rey, Ziegler, & Grainger, 1998). Only an effect that emerged as the common output of experiments using similar designs and stimuli but different tasks should be considered as reliable evidence for motivating a round of revision in successful computational models of visual word recognition. Experiment 2 addressed this issue.

EXPERIMENT 2: PERCEPTUAL IDENTIFICATION

Whereas the inhibitory effect of first syllable frequency in Spanish is well documented for the lexical decision task, there is less evidence for it to appear in experiments using a perceptual identification task. We know of only one study, in which Perea and Carreiras (1995) reported an inhibitory effect of syllable frequency in a progressive demasking task. For low-frequency words there was a significant inhibitory effect of syllable frequency whereas for high-frequency words syllable frequency caused a facilitatory tendency. Perea and Carreiras (1995) pointed out that low-frequency words are, during a longer time, the object of inhibition from competing word candidates and that this time could be prolonged when identification is made difficult as in perceptual identification tasks. However, while a superiority of the effect for low-frequency words might be explained in this way, if the opposite direction of the effect for low- and high-frequency words they reported in their experiment was real, this would create serious problems for this account. Such a possible opposite direction of the influence of syllable frequency in low- and high-frequency words also seems incompatible with the theoretical framework proposed by Carreiras et al. (1993), accounting for the effect by the amount of inhibition caused by competing word candidates as determined by their syllable frequency.

Perhaps, this somewhat strange result might be attributed to task-specific processes induced by the progressive demasking procedure. When presentation time for a stimulus is very short (the duration of the first unmasked presentation of a word in the experiment of Perea and Carreiras (1995) was only 16 ms) only parts of the whole word will probably be recognised. Considering that the optimal viewing position for word recognition is located slightly left of a word's centre (Nazir, Jacobs, & O'Regan, 1998; O'Regan & Jacobs, 1992), in the progressive demasking task the first part of a polysyllabic word to be recognised may often be the first syllable. Now, in the case of low-frequency words, after an early recognition of the first syllable, before the rest of the word is available for further processing, this syllable may activate other word units that could interfere with the processing of the target, because their frequency is superior to the frequency of the target word. High-frequency words are less likely to possess such higher-frequency syllabic neighbours. Yet, it can be assumed that apart from the inhibitory effect of syllable frequency due to lateral inhibition occurring at a lexical level of word processing (Carreiras et al., 1993), the processing of a syllable itself should be enhanced by its frequency. In the progressive demasking task, the high frequency of the first syllable can be an advantage for high-frequency words when this syllable is recognised more easily than a low-frequency syllable. The processing of high-frequency words, which are likely not to have higher-frequency syllabic neighbours, would thus be especially enhanced when the frequency of their first syllable is high. The corresponding word units could thus be quickly activated due to an early availability of their first syllable and would not suffer any inhibition because of the absence of higher-frequency syllabic neighbours.

To avoid such potential problems, we decided to use the fragmentation procedure, as a perceptual identification task that is both widely used in fundamental and applied research (Nuerk, Graf, Boecker, Gauggel & Jacobs, 2002; Snodgrass & Vanderwart, 1980; Snodgrass & Poster, 1992) and well-understood from a computational modelling point of view (Ziegler, Rey, & Jacobs, 1998). In this task, identification of the stimulus is made difficult by fragmentation of all of a word's letters and there is no risk of some parts of a word being systematically available (or processed) before the others, since presentation duration is participant-controlled. If syllable frequency inhibits lexical access, then words with high-frequency syllables should be recognised at later levels of (de)fragmentation than words with low-frequency syllables.

Method

Participants. Twenty-nine students of the Catholic University of Eichstaett-Ingolstadt participated in the experiment to partially fulfil a course requirement. All were native speakers of German and had normal or corrected-to-normal vision.

Design and Materials. The design was the same as in Experiment 1, but another set of 88 stimuli was selected. This modification and reduction of the size of the item set was necessary because an additional variable, letter confusability, had to be controlled for. Depending on a letter's visual features, the levels at which participants are able to identify a single letter when it is presented in the fragmentation test, differ considerably. Ziegler et al. (1998) showed that the mean confusability of all the letters of a word significantly influences the level of identification of whole words. Words are identified on an earlier level when the mean letter confusability is low. To obtain a reliable index of confusability in our presentation conditions using the word fragmentation test, we ran a pre-experiment. Ten subjects identified single letters in the word fragmentation test, each letter being presented ten times in a pseudorandomised order. The resulting mean level of identification for each letter was used as a confusability index to calculate the mean confusability of the stimuli in Experiment 2. With respect to Experiment 1 the ranges defining a syllable as high- or low-frequent were modified. The maximum of frequency of occurrence was now set at 500/million for low-frequency syllables, the minimum value for high-frequency syllables at 3500/million. The range of the levels of the factor word frequency was the same as in Experiment 1 and all variables that had been held constant in Experiment 1 were also controlled for in Experiment 2. The stimuli of Experiment 2 are listed in the Appendix. Characteristics for words in Experiment 2 are given in Table 4.

Procedure. Participants were seated approximately 50 cm in front of a computer screen, while being tested individually in a quiet room. There were six practice trials before the experiment started. Stimuli were presented in uppercase letters. At the beginning of each trial, only 12% of the visual features of each stimulus were visible on the computer screen. All stimulus words had been subjected to a randomised fragmentation procedure. Participants were instructed to activate more parts of each word's visual features by pressing a key, if necessary for identification. Every time they did this, another 12% of the whole word's visual features

TABLE 4
Characteristics of words used in Experiment 2

	WF		*SF1*		*SF2*		*N*		*L*
Word class	*M*	*Range*	*M*	*Range*	*M*	*Range*	*M*	*Range*	*M*
High WF High SF	219	101–709	12225	4066–21,921	1708	234–16,350	1.18	0–5	5.73
High WF Low SF	190	115–392	285	125–488	1905	132–4237	1.86	0–6	5.68
Low WF High SF	3.55	0–9.83	17326	3527–110,013	1158	28–16,350	1.45	0–6	5.68
Low WF Low SF	3.58	0–8	226	58–488	1509	105–4405	1.50	0–4	5.68

Means (M) and ranges of the independent variables word frequency (WF) and frequency of the first syllable (SF1). Means and ranges of variables that were held constant: frequency of the second syllable (SF2), density of orthographic neighbourhood (N) and mean word length (L).

appeared on the screen, until it became fully available on the eighth level of defragmentation. Once a word was identified, it had to be entered into the keyboard. The level, at which this typing response occurred, was recorded as the dependent variable.

Results and Discussion

Mean levels of fragmentation corresponding to correct identifications and error data were submitted to separate ANOVAs. The analysis of the response levels revealed a significant main effect of word frequency, $F_1(1, 28) = 78.34$, $p \leq .0001$; $F_2(1, 84) = 12.83$, $p \leq .0006$. High-frequency words were identified at an earlier level of fragmentation (4.64) than low-frequency words (5.14). More importantly, there also was a significant main effect of syllable frequency in the participant analysis. More defragmentation was necessary to identify words with high-frequency syllables, $F_1(1, 28) = 15.46$, $p \leq .0005$; $F_2(1, 84) = 1.69$, $p \leq .2$; level 4.98 for high, level 4.80 for low syllable frequency. There was no significant interaction between word and syllable frequency. Neither were there any significant effects in the analysis of the error data. There was a tendency for words to provoke more incorrect responses when word frequency was low, with 9.0% errors for words with high word frequency vs. 10.7% errors for low-frequency words. Similarly an inhibitory tendency was caused by syllable frequency with 10.4% errors for words with high-frequency syllables vs. 9.3% errors for low syllable frequency words. Mean levels of identification and percentage of errors for words in Experiment 2 are given in Table 5.

Replicating the main result of the lexical decision task used in Experiment 1, the frequency of a word's first syllable inhibited the process of recognition in the present perceptual identification task, thus generalising the inhibitory effect of syllable frequency reported for the Spanish language to another language and another task environment. Interestingly, this inhibitory effect also appeared in the data for high-frequency words, which had not been the case when Perea and Carreiras (1995) presented

TABLE 5
Mean levels of identification (LI), standard deviation of levels of identification (SD) and percentage of errors for words in Experiment 2

	Word frequency					
	High			*Low*		
Syllable frequency	*LI*	*SD*	*% error*	*LI*	*SD*	*% error*
High	4.73	.60	9.7	5.24	.67	11.1
Low	4.56	.67	8.3	5.04	.60	10.3

Spanish words in the progressive demasking task. The fact that in the word fragmentation task all parts of a word are, if not completely, but simultaneously available might have helped to more precisely reveal the role that syllabic frequency plays for lexical access.

The fact that this inhibitory effect of syllable frequency does not appear in the error data might be due to task-specific processes. Because stimulus presentation time in this task is not limited, errors are generally less likely to occur considering that participants might exclude wrong word candidates by a more extensive analysis of the input than in other perceptual identification or speeded response tasks.

GENERAL DISCUSSION

The results of two experiments using a lexical decision and a perceptual identification task indicate that German words are recognised more slowly when their first syllable is of high frequency than when it is of low frequency. This inhibitory effect of syllable frequency is especially strong for low-frequency words. Such effects of the phonologically defined syllabic structure should only emerge if participants perform in some way a segmentation of the whole word into its phonological subcomponents, the syllables, before or while lexical access to the word is achieved.

At an abstract, information-theoretic level, the effect can be understood as being due to an increased level of uncertainty about the identity of words that start with a high-frequency syllable as compared with words that start with a low-frequency syllable: low-frequency syllables provide more information than high-frequency ones, especially if the processing of polysyllabic words is in some way biased towards their beginning or done in some serial fashion (Álvarez et al., 1998, 2000; see also Taft & Forster, 1976).

At a more algorithmic level, Carreiras et al. (1993), who discovered the syllable frequency effect in Spanish, interpret it in a similar way as a lexical access effect by help of a specific qualitative model of the interactive activation family that includes an additional level of syllabic representations. During the processing of a word, this syllabic level would receive activation from the letter level and would send out activation to all the entries in the word level that share an identified syllable in a specific position with the input. The size of this cohort of competing candidates, the syllabic neighbours, would be modified by syllable frequency. In particular, a word's higher-frequency syllabic neighbours would, by the mechanism of lateral inhibition, interfere with the processing of a target word and thus cause the experimentally observed delays in recognition latencies for words with a high-frequency first syllable. The account of the syllable frequency effect thus is analogous to Grainger and colleagues'

Job No. 3976 MFK-Mendip Page: 385 of 390 Date: 13/5/04 Time: 6:24am Job ID: LANGUAGE SI-2

account of the orthographic neighbourhood frequency effect (Grainger & Jacobs, 1996; Grainger, O'Regan, Jacobs, & Seguí, 1989, 1992). On the one hand one has to be suspicious when using simulation models that represent nonlinear dynamic systems, such as the interactive activation model family, for qualitative accounts of experimental effects. On the other hand the lack of any computational model that could at present simulate this effect and the intuitive appeal of Carreiras et al.'s (1993) account, which seems, at present, the most simple and straightforward one, are reasons to make us adopt this interpretation.

A first step towards implementing such a model has been made with the 'functional units model' (FUM; Rey, 1998; Richter, 1999). Based on the MROM, the FUM has an additional structure of sublexical units (i.e., graphemes) between the letter and word levels that enable it to account for the grapheme effect obtained by Rey et al. (2000). Because alternative computational models such as Zorzi et al.'s (1998) or the revised German DRC (Coltheart et al., 2001; Ziegler et al., 2000) also cannot deal with polysyllabic words, at present it seems in order not to speculate how they could possibly account for the effect (but see Ferrand & New, 2003). The only computational model which incorporates a representation of syllabic structure that we know of can simulate the process of naming of polysyllabic words (Ans et al., 1998) and could thus possibly be used to account for the facilitatory effect of first syllable frequency on naming latencies (Perea & Carreiras, 1996, 1998), but not for the inhibition due to first syllable frequency in recognition tasks. A more general problem for all computational models of word recognition that could, in principle, be modified so as to be able to simulate the present inhibitory syllable frequency effect is the question whether those revised models could still successfully simulate all the other relevant experimental effects in the word recognition field (e.g., the neighbourhood frequency effect). For instance, including a syllabic level of representations might alter the dynamics of the model in a way that requires modifications of important model parameters that were always kept constant in previous, successful simulation studies. These modifications in turn, could lead to different model predictions concerning well established effects. However, what would be gained, if, say, the revised DRC (Coltheart et al., 2001) could simulate the inhibitory syllable frequency effect after the modifications recently proposed by Ferrand and New (2003), but could no longer simulate the inhibitory neighbourhood frequency effect? Given that very little is known about the processing of polysyllabic words as compared with the processing of monosyllabic words (Carreiras & Perea, 2002; Chateau & Jared, 2003), we would like to argue that a good deal of more research should be devoted to the establishment of a set of reliable experimental effects on the processing of polysyllabic words, before intensive computational model revision studies are launched. After all, it could be that the processing of longer, complex polysyllabic words is qualitatively different from the reading of short, monosyllabic, monomorphemic words (e.g., if only because of the involvement of different eye movement patterns). If so, perhaps the development of a new generation of word recognition models would be more promising than trying to shape-up the previous generation.

To sum up, the theoretical significance of the present study can be seen in the fact that, by successfully replicating in a non-Romance language and at least one different task (fragmentation task) the inhibitory effect of syllable frequency, first described by Carreiras et al. (1993) for the Spanish language, it provides evidence for the conclusion that this effect is neither language-, nor task-specific. If so, it cannot be ignored by current computational models of visual word recognition that have been designed to describe the basic mechanisms underlying word recognition in general. Coming back to the quotation starting this paper, we would thus like to conclude that ''any model of lexical access has to incorporate a syllabic level of representations or include the syllable as a sublexical unit of processing in Spanish and German''. Whether the effect can also be found in other Romance or non-Romance languages is an issue for future research. Work is in progress to examine these findings in the French language, in whose historical development syllables have played a much greater role than in German, but in which there is contrasting evidence suggesting that orthographic rather than phonological word subcomponents are functional in visual word recognition (Rouibah & Taft, 2001), or the contrary (Ferrand & New, 2003).

REFERENCES

Álvarez, C.J., Carreiras, M., & De Vega, M. (2000). Syllable-frequency effect in visual word recognition: Evidence of sequential type-processing. *Psicológica*, *21*, 341–374.

Álvarez, C.J., Carreiras, M., & Taft, M. (2001). Syllables and morphemes: contrasting frequency effects in spanish. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *27*, 545–555.

Álvarez, C.J., De Vega, M., & Carreiras, M. (1998). La sílaba como unidad de activación lexica en la lectura de palabras trisílabas. *Psicothema*, *10*, 371–386.

Ans, B., Carbonnel, S., & Valdois, S. (1998). A connectionist multiple-trace model for polysyllabic word reading. *Psychological Review*, *105*, 678–723.

Baayen, R.H., Piepenbrock, R., & van Rijn, H. (1993). *The CELEX Lexikal Database (CD-ROM)*. Philadelphia, PA: Linguistic Data Consortium, University of Pennsylvania.

Carreiras, M., & Perea, M. (2002). Masked priming effects with syllabic neighbors in a lexical decision task. *Journal of Experimental Psychology: Human Perception and Performance*, *28*, 1228–1242.

Carreiras, M., & Perea, M. (in press). Naming pseudowords in Spanish: Effects of syllable frequency in production. *Brain and Language*.

Carreiras, M., Álvarez, C.J., & De Vega, M. (1993). Syllable frequency and visual word recognition in spanish. *Journal of Memory and Language*, *32*, 766–780.

Chateau, D., & Jared, D. (2003). Spelling–sound consistency effects in disyllabic word naming. *Journal of Memory and Language*, *48*, 255–280.

Cohen, J.D., MacWhinney, B., Flatt, M. & Provost, J. (1993). PsyScope: A new graphic interactive environment for designing psychology experiments. *Behavioral Research Methods, Instruments & Computers*, *25*(2), 257–271.

Coltheart, M., Rastle, K., Perry, C., Langdon, R., & Ziegler, J.C. (2001). DRC: A dual route model of visual word recognition and reading aloud. *Psychological Review*, *108*, 204–256.

De Jong, N.H., Schreuder, R., & Baayen, R.H. (2000). The morphological family size effect and morphology. *Language and Cognitive Processes*, *15*, 329–365.

Dominguez, A., De Vega, M., & Cuetos, F. (1997). Lexical inhibition from syllabic units in visual word recognition. *Language and Cognitive Processes*, *12*, 401–422.

Ferrand, L., & New, B. (2003). Syllabic length effects in visual word recognition and naming *Acta Psychologica*, *113*, 167–183.

Ferrand, L., Segui, J., & Humphreys, G.W. (1997). The syllable's role in word naming. *Memory & Cognition*, *25*, 458–470.

Grainger, J., & Jacobs, A.M. (1993). Masked partial-word priming in visual word recognition: effects of positional letter frequency. *Journal of Experimental Psychology: Human Perception and Performance*, *19*, 951–964.

Grainger, J., & Jacobs, A.M. (1996). Orthographic processing in visual word recognition: A multiple read-out model. *Psychological Review*, *103*, 518–565.

Grainger, J., O'Regan, J.K., Jacobs, A.M., & Segui, J. (1989). On the role of competing word units in visual word recognition: the neighborhood frequency effect. *Perception and Psychophysics*, *45*, 189–195.

Grainger, J., O'Regan, J.K., Jacobs, A.M., & Segui, J. (1992). Neighborhood frequency effects and letter visibility in visual word recognition. *Perception and Psychophysics*, *51*, 49–56.

Jacobs, A.M. (1994). On computational theories and multilevel, multitask models of cognition: The case of word recognition. *Behavioral and Brain Sciences*, *17*, 670–672.

Jacobs, A.M., Graf, R., & Kinder, A. (2003). Receiver-operating characteristics in the lexical decision task: evidence for a simple signal detection process simulated by the multiple read-out model. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *29*(3), 481–488.

Jacobs, A.M., & Grainger, J. (1994). Models of visual word recognition: Sampling the state of the art. *Journal of Experimental Psychology: Human Perception and Performance*, *20*, 1311–1334.

Jacobs, A.M., Rey, A., Ziegler, J.C., & Grainger, J. (1998). MROM-P: An interactive activation, multiple read-out model of orthographic and phonological processes in visual word recognition. In J. Grainger, & A.M. Jacobs (Eds.), *Localist connectionist approaches to human cognition*, (pp. 147–187). Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Massaro, D.W., & Cohen, M. (1994). Visual, orthographic, phonological, and lexical influences in reading. *Journal of Experimental Psychology: Human Perception and Performance*, *20*, 1107–1128.

Morais, J., Content, A., Cary, L., Mehler, J., & Seguí, J. (1989). Syllabic segmentation and literacy. *Language and Cognitive Processes*, *4*, 57–67.

Nazir, T.A., Jacobs, A.M., & O'Regan, J.K. (1998). Letter legibility and visual word recognition. *Memory and Cognition*, *26*, 810–821.

Nuerk, H.C., Rey, A., Graf, R., & Jacobs, A.M. (2000). Phonographic sublexical units in visual word recognition. *Current Psychology Letters*, *2*, 25–36.

Nuerk, H.-C., Graf, R., Boecker, M., Gauggel, S., & Jacobs, A.M. (2002). Der Wortfragmentationstest FRAG als computergestütztes Verfahren zur Erfassung der visuellen Worterkennung bei aphasischen und nicht-aphasischen Patienten. *Zeitschrift für Neuropsychologie*, *13*, 3–18.

O'Regan, J.K., & Jacobs, A.M. (1992). Optimal viewing position effect in word recognition: A challenge to current theory. *Journal of Experimental Psychology: Human Perception and Performance*, *18*, 185–197.

Paap, K.R., & Johansen, L.S. (1994). The case of the vanishing frequency effect. *Journal of Experimental Psychology: Human Perception and Performance*, *20*, 1129–1157.

Perea, M., & Carreiras, M. (1995). Efectos de frecuencia silábica en tareas de identificación. *Psicológica*, *16*, 483–496.

Perea, M., & Carreiras, M. (1996). Efectos de frecuencia silábica y vecindad ortográfica en la pronunciación de palabras y pseudopalabras. *Psicológica*, *17*, 425–440.

Perea, M., & Carreiras, M. (1998). Effects of syllable frequency and syllable neighborhood frequency in visual word recognition. *Journal of Experimental Psychology: Human Perception and Performance*, *24*, 134–144.

Rey, A. (1998). *Orthographie et Phonologie dans la Perception des Mots écrits*. Doctoral Dissertation, Université de Provence Aix, Marseille.

Rey, A., Ziegler, J.C., & Jacobs, A.M. (2000). Graphemes are perceptual reading units. *Cognition*, *75*, B1–B12.

Richter, K. (1999). *A functional units model of visual word recognition*. Masters thesis, Philipps-University, Marburg.

Rouibah, A., & Taft, M. (2001). The role of syllabic structure in French visual word recognition. *Memory and Cognition*, *29*, 373–381.

Sebastián-Gallés, N., Dupoux, E., Seguí, J., & Mehler, J. (1992). Contrasting syllabic effects in Catalan and Spanish. *Journal of Memory and Language*, *31*, 18–32.

Seidenberg, M.S. (1987). Sublexical structures in visual word recognition: Access units or orthographic redundancy? In M. Coltheart (Ed.), *Attention and performance XII: The psychology of reading*. Hove, UK: Lawrence Erlbaum Associates Ltd.

Snodgrass, J.G., & Poster, M. (1992). Visual-word recognition thresholds for screen fragmented names of the Snodgrass and Vanderwart pictures. *Behaviour Research Methods, Instruments, and Computers*, *24*, 1–15.

Snodgrass, J.G., & Vanderwart, M. (1980). A standardized set of 260 pictures: Norms for name agreement, image agreement, familiarity and visual complexity. *Journal of Experimental Psychology: Human Perception and Performance*, *6*, 174–215.

Taft, M. (1979). Lexical access via an orthographic code: The basic orthographic syllable structure (BOSS). *Journal of Verbal Learning and Verbal Behaviour*, *18*, 21–39.

Taft, M., & Forster, K.I. (1976). Lexical storage and retrieval of polymorphemic and polysyllabic words. *Journal of Verbal Learning and Verbal Behaviour*, *15*, 638–647.

Wiese, R. (1996). *The phonology of German*. Oxford: Clarendon Press.

Wimmer, H., & Goswami, U. (1994). The influence of orthographic consistency on reading development: Word recognition in English and German children. *Cognition*, *51,* 91–103.

Ziegler, J.C., Perry, C., & Coltheart, M. (2000). The DRC model of visual word recognition and reading aloud: An extension to German. *European Journal of Cognitive Psychology*, *12*, 413–430.

Ziegler, J.C., Perry, C., Jacobs, A.M., & Braun, M. (2001). Identical words are read differently in different languages. *Psychological Science*, *27*, 547–559.

Ziegler, J.C., Rey, A., & Jacobs, A.M. (1998). Simulating individual word identification thresholds and errors in the fragmentation task. *Memory and Cognition*, *26*, 490–501.

Ziegler, J.C., Stone, G.O., & Jacobs, A.M. (1997). What's the pronounciation for _OUGH and the Spelling for /u/? A database for computing feedforward and feedback consistency in English. *Behavior Research Methods, Instruments, and Computers*, *29*, 600–618.

Zorzi, M., Houghton, G., & Butterworth, B. (1998). Two routes or one in reading aloud? A connectionist dual-process model. *Journal of Experimental Psychology: Human Perception and Performance*, *24*, 1131–1161.

APPENDIX

Words for Experiments 1 and 2

List of words used in Experiment 1, differing in word frequency and frequency of the first syllable

High word frequency		*Low word frequency*	
SF high	*SF low*	*SF high*	*SF low*
ANDERS	DIREKT	ADELN	ACHSEL
ANFANG	DOLLAR	ALSTER	BAGGER
AUFBAU	FAHREN	ALTERS	BISON
BEGINN	FIRMA	ANBEI	DIPLOM
BEREIT	GRENZE	ANHAND	ELSTER
BESUCH	GRUPPE	ANTUN	EXTERN
BEVOR	HANDEL	AUFTUN	EXTRA
BEZIRK	HELFEN	BEHEND	FAHRIG
DAHER	HILFE	BESAGT	FASELN
EINIG	HOFFEN	DERLEI	GEISEL
EINZIG	HOTEL	EINHER	GEIZIG
ERFOLG	KIRCHE	ERBEN	GLATZE
GEBIET	KLASSE	ERDIG	GOLFER
GEFAHR	KOSTEN	ERDUNG	GUMMI
GENAU	LEHRER	ERWEIS	HARZIG
GERING	MONTAG	GEDEIH	HECKE
GESAMT	MUSIK	GESELL	KIEFER
GESETZ	NUTZEN	HABIT	MENSA
GEWALT	OPFER	HAPERN	MUSKEL
INDEM	PARIS	INBILD	ORGEL
MITTE	PARTEI	MITHIN	PILGER
MITTEL	PERSON	UMHIN	PINSEL
RECHEN	RUHIG	UNWEIT	PUMPEN
SOGAR	STIMME	VORDEM	TADELN
SOWIE	SYSTEM	WIRBEL	TIGER
UMSATZ	THEMA	WIRTIN	ZIEGEL
VORHER	WARUM	ZUBER	ZIRKA
WIRKEN	ZIMMER	ZULIEB	ZIRKUS

Note: SF = frequency of the first syllable.

List of words used in Experiment 2, differing in word frequency and frequency of the first syllable

High word frequency		*Low word frequency*	
SF high	*SF low*	*SF high*	*SF low*
ANFANG	BITTEN	ABTEI	ACHSEL
AUFBAU	DOLLAR	ABWURF	BLUTEN
BEREIT	FIRMA	ANHAND	DICHTE
BESUCH	GELTEN	AUFTUN	DONNER
BEVOR	GRENZE	BECHER	FUNKEN
DAMALS	GRUPPE	BELEG	GEISEL
DAVON	HILFE	DERLEI	HONIG
DIENEN	KIRCHE	EICHE	LAUNIG
EINIG	LEHRER	EINHER	MALMEN
EINMAL	MONTAG	EINZEL	MENTAL
EINZIG	MUSIK	ERBEN	MUTTI
ERFOLG	ROLLE	ERDUNG	ORGEL
GEBIET	RUFEN	ERKER	PLANE
GENAU	RUHIG	GESELL	RADLER
GESETZ	SCHULE	HAPERN	ROSTIG
INDEM	STIMME	INTUS	RUDERN
MITTEL	SYSTEM	UNMUT	SENKE
SIEBEN	THEMA	UNWEIT	TANGO
SOGAR	TRETEN	VORWEG	TAUMEL
SOWOHL	WARTEN	WIRBEL	TIGER
UMSATZ	ZIEHEN	ZULAUF	TONLOS
WIRKEN	ZIMMER	ZUSATZ	ZIMBEL

Note: SF = frequency of the first syllable.