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Inhibitory effects of first syllable-frequency in lexical decision: An event-related potential study

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Inhibitory effects of first syllable-frequency during lexical decision: An event-related potential study

Abstract

Electrophysiological correlates of the behaviorally well-documented inhibitory effect of first syllable-frequency during lexical access [1, 2, 3, 7, 9, 15, 16, 17] are presented. In a lexical decision task, response times to words with high-frequency first syllables were longer than those to words with low-frequency first syllables and resulted in more negative event-related potentials (ERPs) in an early time window from 190-280 ms and in the N400 component. The onset of the observed first syllable-frequency effect was prior to the onset of the effect of lexicality (i.e., the first reliable differentiation in ERP waveforms in response to words and pseudowords, a potential marker of lexical access). The present study's results support Barber et al.'s [6] notion of the prelexical nature of the first syllable-frequency effect by (A) providing evidence for electrophysiological correlates of first syllable-frequency in another, non-Romance orthography (i.e., German), (B) relating the onset of the first-syllable-frequency effect to the onset of the lexicality effect and (C) strengthening this pattern of results by means of a novel item-based analysis of ERP data. Implications of the prelexical nature of the inhibitory first syllable-frequency effect for computational models of reading, specifically for Ans et al.'s [4] multiple-trace memory (MTM) model of reading are discussed.

Keywords: Event-related potentials; ERP; EEG; word recognition; syllable-frequency; reading; item-based analysis; lexical access

Introduction

A behavioral effect with major impact on word recognition research is the syllable-frequency effect described first by a Spanish research group [1,2,3,7,15,16,17]. During a lexical decision task, words with high-frequency first syllables are responded to more slowly than words with low-frequency first syllables. This pattern of results was interpreted as an inhibitory effect of the first syllable’s frequency on lexical access. In consequence, Álvarez et al. [2] proposed that "any model of lexical access has to incorporate a syllabic level of representation or include the syllable as a sublexical unit of processing in Spanish" (p. 553). Additional importance is lent to this conclusion since the effect of first syllable-frequency could recently be replicated for another, non-Romance orthography: During a lexical decision and a perceptual identification task Conrad & Jacobs [9] could show an inhibitory effect of syllable-frequency for German. Evidence for the notion that (at least in some orthographic systems) the syllable serves as an access unit during lexical processing is insofar of importance, as up to now influential models of word recognition do not include syllabic units of representation [8,10,18] (but see [4]) and research on word recognition focused almost exclusively on monosyllabic words.

To anchor the effect of first syllable-frequency in the time course of visual word recognition more exactly, the analysis of event related potentials (ERPs) during the processing of written words is obviously helpful. Concerning the electrophysiological correlates of the first syllable-frequency effect, a specific prediction can be made since ERP evidence concerning another important effect in visual word recognition, the neighborhood size effect, has previously been reported [11]. The orthographic neighborhood of a specific word is defined as the group of words that are of the same length as the target, but differ from it in only one letter. Large neighborhoods facilitate the responses to words in lexical decision tasks, but inhibit the correct rejection of pseudowords (for a more detailed discussion, see [19]). It is assumed that a target with a large neighborhood activates not only the representation of the word itself, but also the representations of other words in the neighborhood of this word. The summed activation of all activated word representations, that is the global activation, is supposed to facilitate the “yes” response during a lexical decision task [10]. Holcomb and colleagues [11] analyzed the N400 component, which is assumed to be sensitive to semantic aspects of word processing [13,14]. Of theoretical relevance is the finding that ERPs in the N400 time window are more negative when a word has a larger set of semantic associations [12]. Holcomb et al. extended this argument to neighborhood size by arguing that a word with large neighborhoods leads to greater semantic activation, since not only the target word’s representations, but also that of its orthographic neighbors will be activated – resulting in a more negative ERP signal in this time window.

This line of arguments can be extended to the syllable-frequency effect found with polysyllabic words. Carreiras et al. [7] qualitatively interpreted the syllable-frequency effect in terms of a model that contains a syllabic level of representation: During the processing of a specific target word, not only the representation of the word itself, but also the representations of other words that share the first syllable with the target word would be activated. The size of this cohort of competing candidates would be greater with increasing syllable-frequency of the target word. Following the logic of Carreiras et al. [7], due to lateral inhibition mechanisms, the target word’s syllabic neighbors would interfere with the processing of the target word and cause the experimentally observed delays. The activation of a cohort of syllabic neighbors of a word should result in greater semantic activation – and this higher semantic activation, in turn, should result in a more negative ERP in a time window around 400 ms for words with higher frequency first syllables.

In a recent ERP study, Barber and colleagues [6] found more negative ERP potentials in an early time window (after 150 ms) and in the N400 component in response to high first syllable-frequency. Upon the fact that the onset of the first syllable-frequency effect was prior to the onset of the word frequency effect (that was found after 350 ms), the authors proposed that these two effects could be associated with different stages of lexical access: Whereas the effect of word frequency could reflect lexical access, the earlier effect of first syllable-frequency could reflect prelexical processing of words and the activation of lexical candidates. However, Barber and colleagues [6] did not compare the first syllable-frequency effect with the lexicality effect (i.e., the onset of differences in the electrophysiological correlates of word and pseudoword processing). But because lexicality effects precede frequency effects during visual word recognition, in the analysis of ERP data it is useful to compare the first syllable-frequency effect with the lexicality effect. Therefore, the aim of the present study was not only to generalize Barber et al.'s [6] account by the investigation of the electrophysiological correlates of the first syllable-frequency effect in another, non-Romance orthography, but also to examine the notion of the prelexical nature of the first syllable-frequency effect by relating its onset to the onset of the lexicality effect.

Materials and Method

Participants

Participants were eighteen students (11 male and 7 female) from the University of Salzburg (mean age 28 years). All subjects were native speakers of German and had normal or corrected to normal vision and were not paid for participation. In a handedness assessment consisting of 17 items, all subjects scored clearly right handed (mean: 16.6 items).

Stimuli and Procedure

The experimental factor first syllable-frequency (high vs. low) was realized by the use of

110 words (see Tab. 1) selected from the CELEX-database [5], 55 of which had a high-frequency first syllable and 55 had a low-frequency first syllable. The high- and low-frequency first syllable words were matched according to the length of the first syllable, the frequency of the second syllable, word frequency, word-length, neighborhood size, number of higher frequency orthographic neighbors and bigram frequency. To run a lexical decision task, in addition, 110 pseudowords were created by randomly combining existing first syllables with existing second syllables of German words. The resulting letter strings had to be orthographically legal and pronounceable.

Stimulus material was presented in randomized order item per item in yellow color on grey background on a computer screen and participants were instructed to decide as fast and as accurately as possible whether the presented stimulus was a word or not. If presented with an existing German word, subjects had to press the "yes" button of the response box, if presented with a pseudoword they had to press the "no" button. A fixation cross centered on the screen preceded each stimulus for a duration varying between 2,000 and 3,000 ms. The duration of the fixation cross was varied to prevent a phase lock on trial timing. Subsequently, a stimulus was presented for 200 ms centered on the screen, followed by a blank screen for 2,800 ms. The mean duration of a trial was 5,500 ms. Subjects were asked not to move or blink eyes during the presentation of the fixation cross or during the presentation of the stimulus. Short breaks were provided every 56 trials.

EEG Data Acquisition and Analysis

Continuous EEG was recorded from 30 sintered Ag/AgCl electrodes on standard positions (FP1, FP2, Fz, F3, F4, F7, F8, FC1, FC2, FC5, FC6, Cz, C3, C4, T7, T8, CP1, CP2, CP5, CP6, Pz, P3, P4, P7, P8, PO7, PO8, Oz, O1, O2) mounted with a modular elastic cap according to the 10-20 system. Signals were amplified by a Neuroscan 32 channel amplifier system (Neuroscan, El Pas, TX, USA) with a bandpass of .15 Hz to 50 Hz and a 50 Hz notchfilter. All electrodes were recorded referentially against a common linked earlobe reference. The EEG signal was digitized every 4 ms that is with a sampling rate of 250 Hz. To monitor horizontal and vertical eye movements, EOG was recorded bipolar to the left and right and above and below the left eye. All impedances were maintained below 5 kΩ. After eye blink and EEG artifact rejection, ERPs were computed from 100 ms prestimulus to 600 ms poststimulus. Separately for each participant, trials with incorrect responses or responses faster than 300 ms or slower than 2300 ms were excluded from behavioral and electrophysiological analysis (7% of the pseudoword trials, 2% of the word trials).

For a reliable determination of ERP components, root mean square [RMS] transformations (i.e., the square root of the mean of the squared potentials from each common-referenced electrode) were used (plotted in the left half of Figures 2 & 3). Because high overall activity results in high peaks and troughs in the RMS, this transformation aids the identification of evoked components. Four time windows (i.e., 190-280, 280-350, 350-450 and 450-550 ms) were chosen by the visual inspection of the RMS plots; as obvious in the left half of Figures 2 and 3, these time windows correspond to the components obvious in the RMS plots. It is important to note that RMS transformation was only used to determine evoked components. Subsequent statistical analysis for the respective time windows was based on the mean amplitudes of the event related potentials (calculated relative to a 100 ms prestimulus baseline): Statistical analyses were performed on the basis of mean values collapsed for clusters of electrodes in the left anterior (F3, FC1, FC5), right anterior (F4, FC2, FC6), left central (C3, CP1, CP5), right central (C4, CP2, CP6), left posterior (P3, P7, PO7) and right posterior (P4, P8, PO8) region, roughly corresponding to the clusters used by Barber et al. [6]. In the left half of

Figure 2 and 3, the time windows for which a main effect or interaction involving lexicality or first-syllable frequency occurred are highlighted. For these time windows, the mean amplitudes of the electrode clusters in the three regions and the two hemispheres are depicted separately for stimulus type in the right half of Figures 2 (effect of lexicality) and Figure 3 (effect of first syllable-frequency).

Results

Subject based analysis

Response times. Analysis revealed an effect of lexicality with mean response times for words being shorter than mean response times for pseudowords, $t(17) = 4.41$; $p < .001$, $M = 694$ ms and $M = 758$ ms, respectively. An inhibitory effect of first syllable-frequency was indicated by longer response times for words with high first syllable-frequency than for words with low first syllable-frequency, $t(17) = 3.86$; $p < .001$, $M = 709$ ms and $M = 679$ ms, respectively.

Electrophysiological results. As evident in Figure 1 (A) and (B), all stimuli elicited a negative component peaking at ~100 ms (N1), followed by a bimodal positive component peaking at ~150 ms and at ~220 ms. This bimodal component was most probably generated by the offset of the visual presentation after 200 ms. Subsequently (and most prominent at frontal sites), there was a negative component at ~300 ms, followed by positive deflection at ~400ms and a late negativity starting at ~450 ms.

Figure 1 about here

To examine potential effects of lexicality, mean amplitudes for words and pseudowords were submitted to 2 X 2 X 3 repeated measures ANOVAs with lexicality (words vs.

pseudowords), hemisphere (left vs. right) and electrode region (anterior, central and posterior) as within-subject factors. Where appropriate, *df*s were adjusted using Huynh-Feldt correction for the violation of sphericity.

Figure 2 about here

As evident from Figure 1 (A), analysis revealed no main effect or interaction involving lexicality in the 190-280 ms and 280-350 ms time windows. In the 350-450 ms time window, analysis resulted in a lexicality by electrode region interaction, $F(1.22, 20.67) = 10.93$; $MSE = .54$; $p < .01$ (for the relevant means see right half of Figure 2). Post-hoc tests showed that, as depicted in Figure 1 (A), pseudowords resulted in a more negative component in anterior regions, $F(1,17) = 6.50$; $MSE = 2.29$; $p < .05$, but not in central and posterior regions, $F < 2.13$ and $F < 1$, respectively. For the 450-550 ms time window, a lexicality by electrode region interaction, $F(1.23, 20.82) = 4.09$; $MSE = .95$; $p < .05$, restricted the main effect of lexicality, $F(1,17) = 5.60$; $MSE = 7.66$; $p < .05$ (for the relevant means see right half of Figure 2). Post-hoc tests revealed, that in this late time window (as illustrated in Figure 1 A), pseudowords resulted in more negative potentials than words in central, $F(1,17) = 9.34$; $MSE = 3.02$; $p < .01$, and posterior regions, $F(1,17) = 5.49$; $MSE = 2.91$; $p < .05$, but not in the anterior region, $F < 1.52$.

To examine potential effects of first syllable-frequency, mean amplitudes for words with high-frequency first syllables and for words with low-frequency first syllables were submitted to 2 X 2 X 3 repeated measures ANOVAs with first syllable-frequency (high vs. low), hemisphere (left vs. right) and electrode region (anterior, central and posterior) as within-subject factors. Where appropriate, *df*s were adjusted using Huynh-Feldt correction for the violation of sphericity.

Figure 3 about here

In the 190-280 ms time window, analysis resulted in a first syllable-frequency by electrode region interaction, $F(1.58, 26.80) = 3.53$; $MSE = .48$; $p < .05$ (see right half of Figure 3 for the relevant means). Post-hoc tests revealed that – as obvious in Figure 1 (B) - words beginning with high-frequency first syllables resulted in a more negative component than words beginning with low-frequency first syllables in frontal regions, $F(1,17) = 6.42$; $MSE = 2.09$; $p < .05$. No such effect of first syllable-frequency was found for central and posterior regions, $F < 2.92$ and $F < 1$, respectively. In the 280-350 ms and the 350-450 ms time window, no main effect or interaction involving first syllable-frequency was found reliable. In the 450-550 ms time window, analysis resulted in a main effect of first syllable-frequency of borderline reliability, $F(1,17) = 4{,}33$; $MSE = 8{,}64$; $p = .053$, which was restricted by a first syllable-frequency by hemisphere interaction, $F(1,17) = 5.21$; $MSE = .17$; $p < .05$ (see right half of Figure 3 for the relevant means). Post-hoc tests revealed that, as depicted in Figure 1 (B), in the left hemisphere words with high-frequency first syllables resulted in more negative potentials than words with low-frequency first syllables, $F(1,17) = 6.13$; $MSE = 4.08$; $p < .05$, however, such an effect was not found reliable for the right hemisphere, $F < 2.83$.

Item based analysis

In order to check whether the effects reported above could also be generalized across the specific stimulus material, the theoretically relevant effects that proved to be reliable in subject based analysis (F_1) were tested in a subsequent item based analysis (F_2). Item means were based upon exactly the same responses as in the subject based analysis (i.e., the same exclusion criteria took effect). However, only items whose means were based upon the response times and the EEG trials of at least 12 subjects were submitted to analysis; this led to the exclusion of ten words and four pseudowords. For the analysis of the binary coded predictor lexicality (word vs. pseudoword), a *t*-test (response times) and ANOVAs (electrophysiological results) were performed using items (instead of subjects) as cases. For the analysis of the more fine-grained measure first syllable-frequency a regression analysis was conducted. A regression analysis with five predictors (log of word frequency, log of first syllable-frequency, log of second syllable-frequency, number of higher frequency [first] syllabic neighbors and number of higher frequency orthographic neighbors) was performed on response times. For the electrophysiological results regression analyses with the same five predictors were performed on mean amplitudes (collapsed for the specific regions, for which the effect of first syllable-frequency was found reliable in the subject based analysis reported above). Backward elimination regression was chosen to circumvent the problem of collinearity – high correlations were found between the predictors first syllable-frequency and number of higher frequency syllabic neighbors ($r[110] = .70$; $p < .001$) and between second syllable-frequency and higher frequency (orthographic) neighbors ($r[110] = .52$; $p < .001$).

Response times. Analysis revealed that the effect of lexicality was also reliable in the item based analysis, $t(212) = 5.73$; $p < .0001$. Concerning the effect of first syllable-frequency, the regression model was significant, $F(3,97) = 15.32$; $p < .0001$; $R^2 = .33$; adj. $R^2 = .31$. The regression revealed that higher first syllable-frequency prolonged response times, $t(97) = 2.02$; $p < .05$; $b = 2.02$, but higher second syllable-frequency and higher word frequency shortened response times, $t(97) = 3.03$; $p < .01$; $b = -.27$ and $t(97) = 4.85$; $p < .0001$; $b = -.42$, respectively.

Electrophysiological results. To re-examine the effect of lexicality on an item basis, mean amplitudes of words and pseudowords were submitted to a 2 X 2 X 3 repeated measures

ANOVA with lexicality (words vs. pseudowords) as between-item factor and hemisphere (left vs. right) and electrode region (anterior, central and posterior) as within-item factors. Where appropriate, *df*s were adjusted using Huynh-Feldt correction for the violation of sphericity. In the 350-450 ms time window, where the subject-based analysis revealed a lexicality by electrode region interaction, the lexicality by electrode region interaction was also reliable on item basis, $F(1.27, 263.03) = 9.92$; $MSE = 3.19$; $p < .001$. Post-hoc tests again revealed this effect to be reliable in frontal regions, $F(1,207) = 9.98$; $MSE = 9.69$; $p < .01$. In the 450-550 ms time window, the reported main effect of lexicality was reliable on item basis, $F(1,207) = 9.61$; $MSE = 30.82$; $p < .01$. On item basis, this main effect of lexicality was only restricted by a lexicality by hemisphere interaction of borderline reliability, $F(1,207) = 3.62$; $MSE = 1.64$; $p = .059$, since post-hoc tests revealed a reliable effect of lexicality in both, left and right hemisphere, $F(1,207) = 11.77$; $MSE = 16.40$; $p < .001$ and $F(1,207) = 6.80$; $MSE = 16.07$; $p < .01$, respectively.

In subject based analysis, the effect of first syllable-frequency was reliable in the 190-280 ms time window in frontal regions. For purposes of testing this effect on an item basis, the mean amplitudes of all electrodes in this (left and right) frontal region (F3, F4, FC1, FC2, FC5 and FC6) were collapsed; upon this combined measure a regression analysis was conducted. The model was reliable, $F(3,97) = 5.63$; $p < .001$; $R^2 = .15$; adj. $R^2 = .13$. The regression revealed that higher first syllable-frequency and higher word frequency resulted in more negative potentials, $t(97) = 2.34$; $p < .05$; $b = -.23$ and $t(97) = 2.27$; $p < .05$; $b = -.22$, respectively. In contrast, higher second syllable-frequency resulted in more positive potentials, $t(97) = 2.14$; $p < .05$; $b = .21$. Since subject-based analysis had revealed a left hemispheric effect of first syllable-frequency in the 450-550 ms time window, mean amplitudes of the electrodes in all (anterior, central and posterior) clusters in the left hemispheric clusters (F3, FC1, FC5, C3, CP1, CP5, P3, P7, PO7) were collapsed and submitted to regression analysis. The model was reliable, $F(3,97) = 6.82$; $p <$

.0001; $R^2 = .18$; adj. $R^2 = .15$. The regression revealed that higher first syllable-frequency and greater number of higher frequency (orthographic) neighbors resulted in more negative potentials, $t(97) = 2.14$; $p < .05$; $b = -.21$ and $t(97) = 3.27$; $p < .01$; $b = -.37$, respectively. In contrast, higher second syllable-frequency resulted in more positive potentials, $t(97) = 2.92$; $p < .01$; $b = .33$.

Correlation between behavioral and electrophysiological results. To examine the relationship between the items' mean amplitudes and the items' mean response times, mean amplitudes of the electrodes in all clusters were collapsed in the 450-550 ms time window. Analysis revealed a high correlation between this electrophysiological measure and the response times, $r(100) = -.41$; $p < .0001$.

Discussion

Concerning the present study's ERP results, the first and most prominent finding is that the early electrophysiological correlate of high first syllable-frequency reported by Barber et al. [6] does also hold true in another, non-Romance orthography: German. A similar early negativation in frontal regions in response to high first syllable-frequency was found (although slightly later, after 190 ms compared to 150 ms in [6]). Furthermore, in the present study high first syllable-frequency also resulted in a more negative N400 effect.

However, in contrast to [6], for the examination of the time course of the first syllable-frequency effect and lexical access, in the present study the onset of first syllable-frequency effect was not contrasted with the onset of the word frequency effect (as in [6]), but with the onset of the lexicality effect. The effect of lexicality (i.e., more negative potentials in response to pseudowords than in response to words) was found in the 350-450 ms and the 450-550 ms time window and therefore subsequent to the effect of first syllable-frequency.

A further important extension of the present study is that the negativation of the ERP in response to high first syllable-frequency words also holds true in an item-based analysis that tests for the generalizability of an effect over items. The results of this reanalysis grant – besides the high correlation between behavioral and electrophysiological measures on the item level – for a high quality of recording and put the observed effect of first syllable-frequency in electrophysiological measures on a firm footing. On the behavioral level, the regression analysis (that explained over 30 % of the items' response time variance) revealed a direct, inhibitory (and well documented, [1, 2, 3, 7, 9, 15, 16, 17]) influence of first syllable-frequency on response times and therefore provides the behavioral prerequisite for an interpretation of the electrophysiological correlates of this effect.

Besides this inhibitory effect of first syllable-frequency, the regression analysis also revealed a facilitatory effect of second syllable-frequency (as described by [1] and [3]) and a facilitatory effect of word frequency on response times. On the electrophysiological level, the regression analysis in the early 190-280 ms time window (that explained over 12% of the mean amplitudes' variance) revealed that higher first syllable-frequency and higher word frequency resulted in more negative potentials. In contrast, second syllable-frequency seems to have a different effect: Comparable to the facilitatory effect in response times, higher second-syllable-frequency did not result in more negative but in more positive potentials. In the latter 450-550 ms time window, the regression analysis (that explained over 15 % of the items' mean amplitudes variance) again showed that higher first syllable-frequency resulted in more negative potentials and higher second syllable-frequency resulted in more positive potentials. Clearly, one has to be cautious in drawing strong inferences upon effects of second syllable-frequency, because they could only be tested for reliability in item-based analysis, but (because second syllable-frequency was not an experimental factor) not in subject-based analysis – clearly more research is necessary concerning this early effect of second syllable-frequency. This restriction holds also true for the finding from item based analysis that a greater number of higher frequency (orthographic) neighbors resulted in more negative potentials.

The present electrophysiological results support Carreiras, Alvarez, and de Vegas's [7] qualitative account of the syllable-frequency effect. The authors proposed that the inhibitory effect of high-frequency first syllables reflects the activation of the representations of competing syllabic neighbors: During the processing of a target word, not only the representation of the target word itself, but also a cohort of representations of words that shares the first syllable with the target would be activated. Following the logic of Holcomb et al. [11], the activation of these competing syllabic neighbors results in a higher semantic load, which in turn should result in a more negative ERP. Therefore, a more negative ERP was expected in response to words with high-frequency first syllables than in response to words with low-frequency first syllables. Of course, this line of arguments does not only hold true for a cohort of representations of syllabic neighbors, but also for a cohort of representations of higher frequency orthographic neighbors: In fact, in the latter time window, negativation in the ERP not only increased with higher first syllable-frequency, but also with a greater number of higher frequency orthographic neighbors.

Apart from the repeated evidence that first syllable-frequency does in fact inhibit lexical access (and its subsequent implication that models of lexical access need to include a syllabic level of representation), it is the evidence of an effect of first syllable-frequency prior to lexical access that further constrains models of visual word recognition. Up to now, the only computational model of reading that provides the necessary prerequisite to account for the inhibitory effect of first syllable-frequency (i.e., the implementation of syllabic processing units) is the multiple-trace memory (MTM) model for polysyllabic word reading by Ans et al. [4]. In this feedforward model, two distinct reading mechanisms are implemented: Global reading (coding information about whole words) and analytic reading (coding information about word segments, most often syllables). However, the fact that a letter string presented to the MTM is always processed in the global reading mode first, questions a successful prediction of the inhibitory effect of first syllable-frequency by this model. Within the MTM, about 97.5% of all words are recognized during global reading (which applies knowledge about whole words and excludes syllable-specific information) and do not undergo any further analytic processing. Only for very low-frequency words and pseudowords the global reading procedure fails and the letter string is processed syllable by syllable in the analytic reading mode. Moreover one has to keep in mind that even these very rare stimuli are checked upon their lexicality by the global reading mode first and only in a second step are submitted to analytic reading. Therefore, also for low-frequency words and pseudowords, the MTM would not be capable to simulate an effect of syllable-frequency that is prior to lexical access.

To conclude, the present results suggest that future models of lexical access need to implement syllabic levels of representation and have to give more weight to the first syllable as a prelexical unit mediating lexical access. Whereas Barber et al. [6] suggest a possible association of the first syllable-frequency effect with phonological processing, evidence from a case study of a patient with an acquired reading disorder also suggests an orthographic locus of the syllable-frequency effect [20]. Moreover, in future research on word recognition the item-based analysis of ERP data of lexical access might be a promising issue.

References

[1] Álvarez, C.J., Carreiras, M. and de Vega, M., Syllable-frequency effect in visual word recognition: Evidence of sequential-type processing, Psicológica, 21 (2000) 341-374.

[2] Álvarez, C.J., Carreiras M. and Taft M., Syllables and morphemes: Contrasting frequency effects in Spanish, J. Exp. Psychol. Learn., 27 (2001) 545-555.

[3] Álvarez, C.J., de Vega M. and Carreiras M., The syllable as an activational unit in reading trisyllabic words, Psicothema, 10 (1998) 371-386.

[4] Ans, B., Carbonnel, S. and Valdois, S., A connectionist multiple-trace memory model for polysyllabic word reading, Psychol. Rev., 105 (1998) 678-723.

[5] Baayen, R. H., Piepenbrock, R. and van Rijn, H., The CELEX Lexical Database (CD-ROM), Linguistic Data Consortium, Philadelphia, 1993.

[6] Barber, H., Vergara, M. and Carreiras, M., Syllable-frequency effects in visual word recognition: evidence from ERPs, Neuroreport, 15 (2004) 545-548.

[7] Carreiras, M., Alvarez, C.J. and de Vega, M., Syllable frequency and visual word recognition in Spanish, J. Mem. Lang., 32 (1993) 766-780.

[8] Coltheart, M., Rastle, K., Perry, C., Langdon, R. and Ziegler, J., DRC: A dual route cascaded model of visual word recognition and reading aloud, 108 (2001) 204-256.

[9] Conrad, M. and Jacobs, A.M., Replicating syllable-frequency effects in Spanish in German: One more challenge to computational models of visual word recognition, Lang. Cognitive Proc., (in press).

[10] Grainger, J. and Jacobs, A.M., Orthographic processing in visual word recognition: A multiple read-out model, Psychol. Rev., 103 (1996) 518-565.

[11] Holcomb, P.J., Grainger, J. and O'Rourke, T., An electrophysiological study of the effects of orthographic neighborhood size on printed word perception, J. Cognitive Neurosci., 14

(2002) 938-950.

[12] Kounios, J. and Holcomb P.J., Structure and process in semantic memory – evidence from event-related brain potentials and reaction-times, J. Exp. Psychol. Gen., 121 (1992) 459-479.

[13] Kutas, M. and Hillyard, S.A., Reading senseless sentences – brain potentials reflect semantic incongruity, Science, 207 (1980) 203-205.

[14] Kutas, M. and Hillyard, S.A., Brain potentials during reading reflect word expectancy and semantic association, Nature, 307 (1984) 161-163.

[15] Perea, M. and Carreiras, M., The effects of syllable frequency in identification tasks, Psicológica, 16 (1995) 483-496.

[16] Perea, M. and Carreiras, M., The effects of syllabic frequency and orthographic neighborhood on the pronunciation of words and pseudo words, Psicológica, 17 (1996) 425-440.

[17] Perea, M. and Carreiras, M., Effects of syllable frequency and syllable neighborhood frequency in visual word recognition, J. Exp. Psychol. Hum. Percept. Perform., 24 (1998) 134-144.

[18] Plaut, D.C., McClelland, J.L., Seidenberg, M.S. and Patterson, K., Understanding normal and impaired word reading: Computational principles in quasi-regular domains, Psychol. Rev., 103 (1996) 56-115.

[19] Pollatsek, A., Perea, M., & Binder, K. (1999). The effects of neighborhood size in reading and lexical decision. *Journal of Experimental Psychology: Human Perception and Performance, 25,* 1142-1158

[20] Stenneken, P., Conrad, M., Goldenberg, G. and Jacobs, A.M., Visual processing of lexical and sublexical units in dyslexia, Brain Lang., 87 (2003) 137-138.

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Figure Captions

Figure 1. Grand average event-related potentials (averaged over items and subjects) at six representative electrodes for the theoretically relevant effect of (A) lexicality with waveforms for words and pseudowords and (B) first syllable-frequency with waveforms for words with high-frequency and low-frequency first syllables. Negative voltage is up and word onset is a 0 ms.

Figure 2. Root mean square potentials (RMS, left half) for words and pseudowords. The two time windows during that a main effect or an interaction involving lexicality occurred are highlighted and the corresponding relevant means of the electrode clusters are plotted separately for stimulus type, region and hemisphere (right half).

Figure 3. Root mean square potentials (RMS, left half) for words with high-frequency first syllables and words with low-frequency first syllables. The two time windows during that a main effect or an interaction involving first syllable-frequency occurred are highlighted and the corresponding relevant means of the electrode clusters are plotted separately for stimulus type, region and hemisphere (right half).

Tables

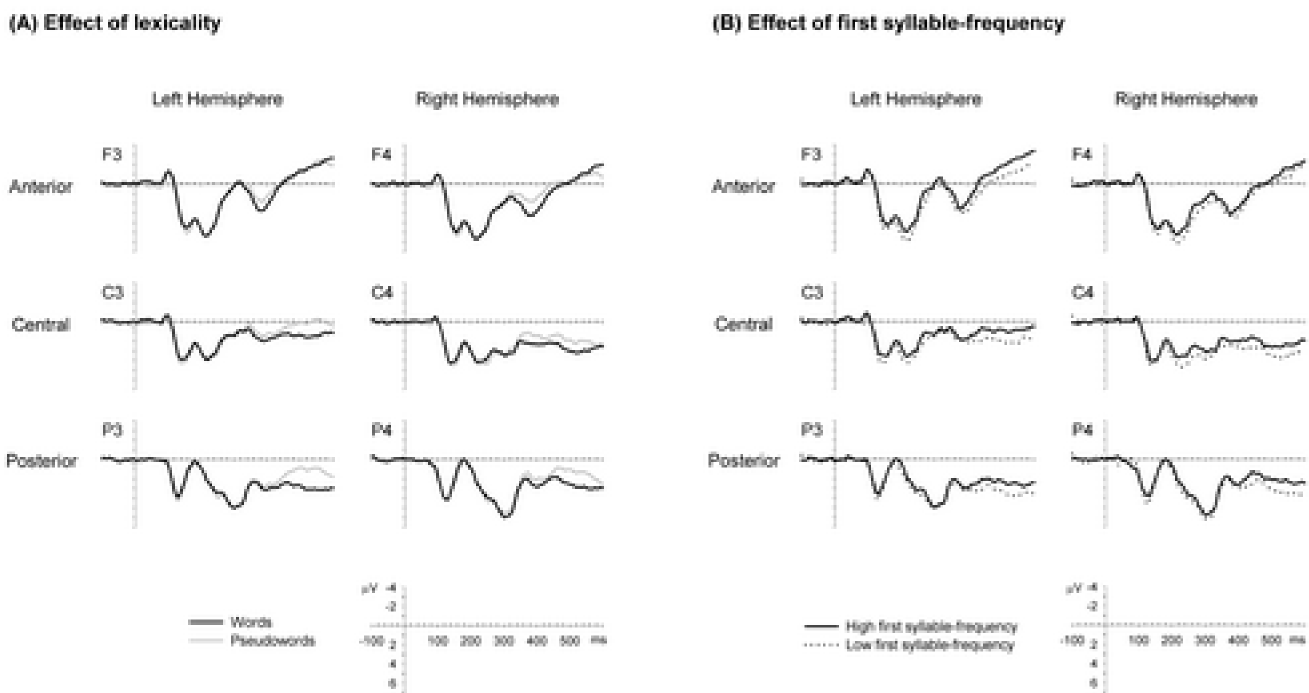
Table 1

Characteristics of word stimuli

	High syllable-F	Low syllable-F
First syllable-F [per million]	7,051 [a]	132 [a]
Length of first syllable [letters]	2.65	2.78
Second syllable-F [per million]	12,907 [a]	15,148 [a]
Word frequency [per million]	9.05	8.51
Word length [letters]	5.44	5.42
Neighborhood size [N]	2.85	2.80
Higher frequent neighbors [N]	1.29	1.36
Bigram frequency [per million]	9,655	8,746

Note. Syllable-F: Syllable-frequency. [a] Summed positional frequency.

Figure 1



(A) Effect of lexicality
(B) Effect of first syllable-frequency
Left Hemisphere
Right Hemisphere
Anterior
Central
Posterior
F3
F4
C3
C4
P3
P4
Words
Pseudowords
High first syllable-frequency
Low first syllable-frequency
µV
ms

Figure 2

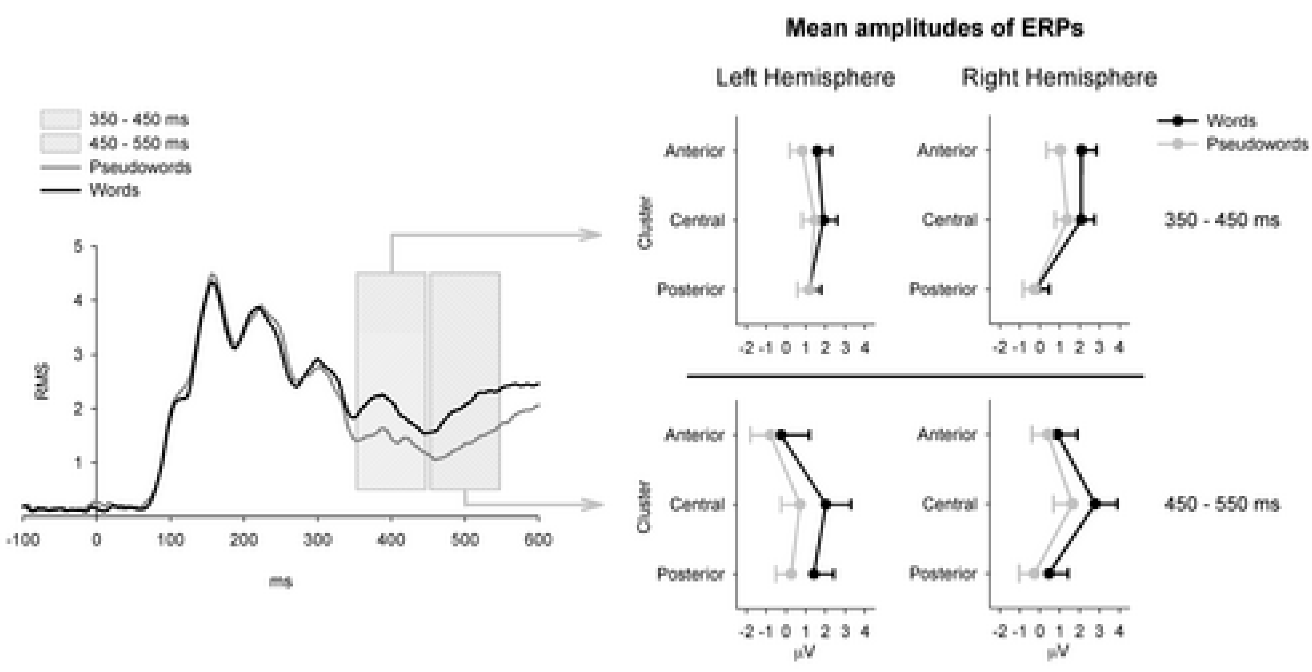
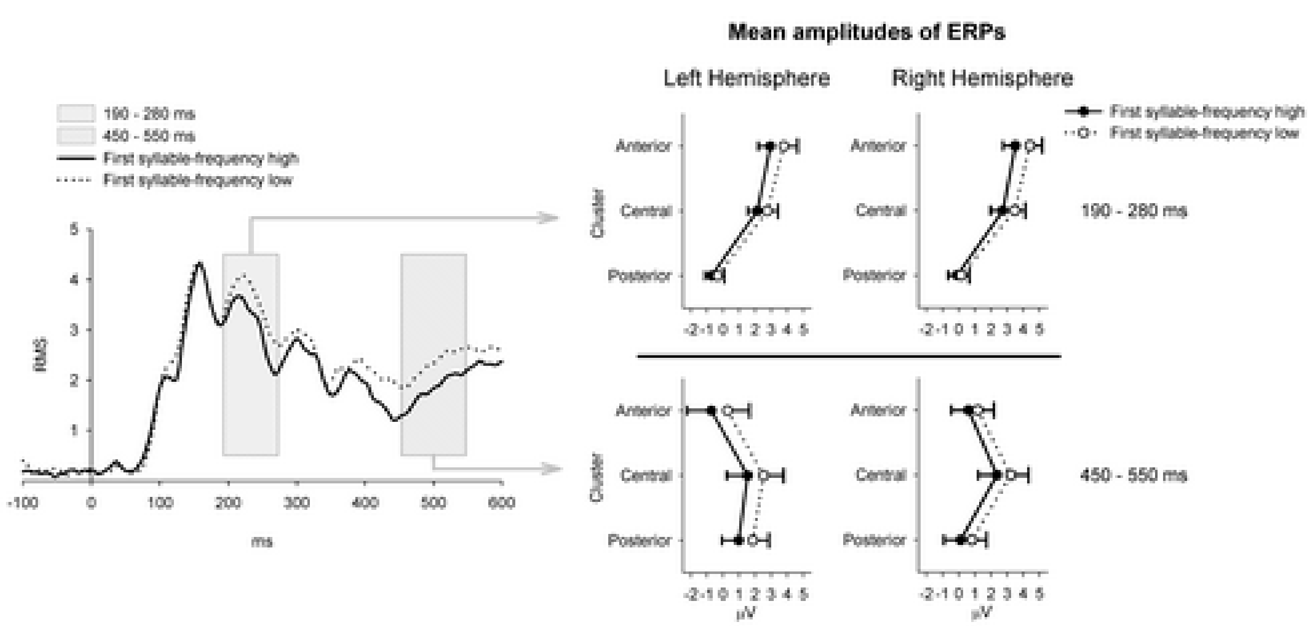

Mean amplitudes of ERPs
Left Hemisphere
Right Hemisphere
Words
Pseudowords
350 - 450 ms
450 - 550 ms
Pseudowords
Words
RMS
ms
Cluster
Anterior
Central
Posterior
µV

Figure 3



190 - 280 ms
450 - 550 ms
First syllable-frequency high
First syllable-frequency low
RMS
ms
Mean amplitudes of ERPs
Left Hemisphere
Right Hemisphere
Anterior
Central
Posterior
Cluster
μV
190 - 280 ms
450 - 550 ms