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A thousand words are worth a picture: Snapshots of printed word processing in an ERP megastudy

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Abstract

Approximately 1000 words were presented to 75 participants in a go/no-go lexical decision task while recording event-related potentials (ERPs). Partial correlations were computed for variables selected to reflect orthographic, lexical, and semantic processing, as well as a novel measure of the visual complexity of written words. Correlations were based on the item-level ERPs at each electrode site and time slice while applying a False Discovery Rate correction. Early effects of visual complexity were seen around 50 ms post-word onset, followed by the earliest sustained orthographic effects around 100-150 ms, and with the bulk of orthographic and lexical influences arising after 200 ms post-word onset. Effects of a semantic variable (concreteness) emerged later, at around 300 ms post-word onset. The overall time-course of these ERP effects is in line with hierarchical, cascaded, interactive accounts of word recognition in which fast feed-forward influences are consolidated by top-down feedback via recurrent processing loops.

Keywords

ERPs; megastudies; visual word recognition; item-level ERPs; visual complexity

INTRODUCTION

The last decade has been witness to an increasing number of large-scale behavioral investigations of visual word recognition. In so-called “megastudies”, a large number of responses are collected for each of a large sample of words, enabling item-level analyses to be performed on the dataset (e.g., Balota et al., 2007; Dufau et al., 2011; Ferrand et al., 2010; Keulers et al., 2012). However, behavior is behavior, and as such can only be measured at the very end-point of processing. Therefore, given the importance in specifying the relative timing of component processes in reading (e.g., Grainger & Holcomb, 2009), we

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AUTHORSHIP
Stéphane Dufau analyzed the data, prepared all graphics, and participated in the writing. Jonathan Grainger participated in the design of the study and wrote the first draft. Katherine Midgley participated in setting up the experiment and supervised the data collection. Phillip Holcomb designed the study and participated in the data analyses and writing.

might be well-advised to look elsewhere for appropriate data, and there is one measurement technique that is particularly well-suited for such an endeavor. This technique involves the millisecond- by-millisecond recording of the brain's electrical activity, and time-locking this activity (the EEG signal) to the onset of a given stimulus in order to measure changes in electrical activity that are provoked by a given stimulus or category of stimuli - the so-called event-related potential (ERP).

By generating item-level data for a large set of items, megastudies provide the opportunity to explore effects of different variables in a parametric, continuous manner (see Balota, Yap, Hutchinson, & Cortese, 2012; Brysbaert, Keulers, & Pawel, 2014, for a review of the advantages of the megastudy approach). For these purposes, megastudies apply correlational approaches to data analysis.[1] Highly relevant for the present work, therefore, are prior studies that have applied regression analyses on item-level ERP data in order to examine the timing of component processes in visual word recognition. Here we first summarize the results of this prior research before describing our megastudy in more detail (see Dien, Frishkoff, Cerbone, & Tucker, 2003, for an early application of this general approach to the study of word comprehension in sentence contexts, and Rey, Dufau, Massol, & Grainger, 2009, and Madec, Rey, Dufau, Klein, & Grainger 2012, for item-level ERP analyses with letter stimuli).

In one large-scale study, Laszlo and Federmeier (2011) tested 120 participants with 75 words and various kinds of nonword stimuli. Regression analyses were performed on item-level ERPs obtained from six electrode sites selected to best capture the N400 ERP component. Orthographic neighborhood and number of semantic associates were both found to significantly influence N400 amplitude. In a follow-up study, Laszlo and Federmeier (2014) performed further regression analyses of the same ERP data set, using variables designed to cover orthographic, lexical, and semantic effects, and correcting for the multiple comparisons that such analyses involve. The earliest reliable effects were seen between 130 to 150 ms, in the form of effects of a composite “orthographic” variable combining bigram frequency, orthographic neighborhood size, and orthographic neighborhood frequency.

Other studies have revealed even earlier effects of orthographic and lexical variables on ERPs. Hauk, Davis, Ford, Pulvermüller, and Marslen-Wilson (2006) tested 20 participants with 300 words presented intermixed with an equal number of nonword stimuli in a lexical decision task. A principal components analysis was used to construct a small number of composite variables. The results revealed an early orthographic effect (combining word length and n-gram frequency) at around 90 ms post-stimulus onset, and a slightly later effect of lexical frequency at 110 ms post-stimulus onset. These findings were confirmed in a follow- up study (Hauk, Pulvermüller, Ford, Marslen-Wilson, & Davis, 2009) that revealed an effect of word length and orthographic neighborhood starting around 100 ms after word onset. Amsel (2011) tested 28 participants with 207 words, and analyzed effects of word length, word frequency, and a host of semantic variables using linear mixed-effects models

[1]We would also point out that megastudies provide databases that can be used to perform “virtual” factorial experiments (e.g., Kuperman, 2015), and clearly the more items there are in the database the more possibilities there are to perform such virtual experiments.

applied to single trial ERPs. Like Hauk et al. (2006; 2009), Amsel found an early effect of word length starting around 110 ms and peaking at around 250 ms, but found effects of word frequency arising much later than in the Hauk et al. (2006) study.

One key comparison point is missing in all these prior studies. That is the influence of purely visual factors[2] that can be used as a benchmark against which the timing of downstream orthographic and lexical influences can be evaluated. As noted by Laszlo and Federmeier (2014), effects of word frequency found before 100 ms post-word onset (e.g., Sereno & Rayner, 2003) merit a certain amount of suspicion given current knowledge of the timing of visual object identification processes, plus the difficulties associated with controlling for the very large number of statistical comparisons that ERP time-course analyses can involve. In the present study, 75 participants were tested with 960 words in a go/no-go lexical decision task, where “go” responses were made to nonword stimuli presented approximately every 10 trials. The main aim of the analyses to be presented here was to compare the timing of purely visual effects with orthographic, lexical, and semantic influences, and to examine the evolution of these effects over time. To do so we selected seven variables hypothesized to be sensitive to various combinations of visual, orthographic, lexical, and semantic processing. These are: 1) visual complexity; 2) proportion of consonants vs. vowels; 3) mean positional bigram frequency; 4) word length in letters; 5) orthographic similarity with other words; 6) word frequency; and 7) concreteness. We expect the sensitivity of ERP recordings to millisecond-by-millisecond changes in brain activity, combined with the high power of the experiment (75 participants tested with 960 words), to reveal the earliest influences of visual processing followed by subsequent orthographic, lexical, and semantic influences.

METHODS

Participants

Seventy-five healthy volunteers (36 male, average age = 20.4 years, range 18-25 years) from Tufts University took part in the experiment as paid volunteers. All participants were right-handed native speakers of English and reported having normal or corrected-to-normal vision. The number of participants was predetermined as being sufficient to obtain at least 40 data points per word, after data loss, for item-based correlation analyses (see the ERP analysis section for further details). No participants were excluded prior to analysis.

Design and stimuli

Nine hundred and sixty nouns between 4 and 8 letters in length were used as the critical stimuli in this study. To these critical words were added 140 nonword items which served as probes in a go-no-go lexical decision task in which participants were instructed to respond with their right index finger as fast as possible whenever they detected a nonword. They were instructed to withhold button presses for the remaining *critical* real word items. Pronounceable, orthographically legal nonwords were formed by replacing one or two

[2]Word length could be considered to be a visual variable, but the visual component of word length (i.e., physical length) is completely confounded with its orthographic component (i.e., length in letters) in all the above-cited studies.

letters in internal positions of real words that were not in the list of critical items. Stimuli were presented as white letters on a black background on a 19-inch CRT monitor in lowercase Arial font. Viewing distance was 120 cm and all words subtended between 1 degree (4 letters) and 2 degrees (8 letters) of horizontal visual angle. Each trial began with a 400 ms presentation of a letter string followed by a 600 ms black screen. Participants were instructed to minimize blinking during the task and were given short one minute rest breaks every 55 trials and a longer four minute break between each of four blocks for 275 trials.

EEG recording procedure

After completing informed consent and handedness forms, participants were seated in a comfortable chair in sound attenuated darkened room. An electro-cap with tin electrodes was used to record continuous EEG from 29 sites on the scalp including sites over left and right fronto-polar (FP1/FP2), frontal (F3/F4, F7/F8), frontal-central (FC1/FC2, FC5/FC6), central (C3/C4), temporal (T7/T8), central-parietal (CP1/CP2, CP5/CP6), parietal (P3/P4, P7/P8), and occipital (O1/O2) areas and five midline sites over the frontal pole (FPz), frontal (Fz), central (Cz), parietal (Pz) and occipital (Oz) areas (see Figure 2). In addition, four electrodes were attached to the face and neck area: one below the left eye (to monitor for vertical eye movement/blinks), one to the right or the right eye (to monitor for horizontal eye movements), one over the left mastoid (reference) and one over the right mastoid (recorded actively to monitor for differential mastoid activity). All EEG electrode impedances were maintained below 5 kΩ (impedance for eye electrodes was less than 10 kΩ). The EEG was amplified by an SA Bioamplifier with a bandpass of 0.01 and 40 Hz and the EEG was continuously sampled at a rate of 250 Hz.

ERP analysis

The ERP data were time-locked to word presentation and were recorded for 960-msec post-target onset with a 100-msec pre-target baseline. A semi-automated method (automatic threshold-based detection and manual confirmation) was used to reject epochs with eye movements, blinks, or muscle artifacts. Each grand-averaged word ERP was calculated by averaging the unique waveform from each participant generated by a given word. The minimal number of artifact-free trials per word was 43 (M=60.01, SD=3.76, range [43, 71]), giving an acceptable signal-to-noise ratio for the entire set of stimuli. On average, the pool of participants used to form each of the grand-averaged word ERPs overlapped by 65.57% (SD=0.06, range [0.33, 0.89]).

Statistical analysis

For each time sample (4 ms) and each of the 29 scalp electrodes, a vector of 960 ERP values (corresponding to the 960 different words) was first extracted from the dataset. For each ERP vector, outliers (mean +/− 2 standard deviations) were removed and seven two-tailed linear partial correlations were computed. The seven variables that the ERP vector was partially correlated with were: CONCRETENESS (M=4.37, SD=1.14, range [1.65, 6.90]) measured in a separate experiment[3]; WORD FREQUENCY (Celex log frequency: Baayen, Piepenbrock and Gulikers, 1995; M=2.44, SD=0.81, range [0.30, 4.1]); ORTHOGRAPHIC DISTANCE (OLD20: Yarkoni et al., 2008; M=2.15, SD=0.70, range [1.00 8.00]) defined as the average Levensthein Distance of the 20 most orthographically similar words, where orthographic similarity is calculated as the minimum number of letter substitutions, deletions, additions or transpositions required to transform one word into another; NUMBER OF LETTERS (M=6, SD=1.41, range [4 8]); BIGRAM FREQUENCY (mean positional bigram frequency: Balota et al., 2007; M=532.34, SD=219.27, range [81.25 1369.3]); CONSONANT-VOWEL PROPORTION, calculated by dividing the number of consonants in a word by the number of letters (M=0.61, SD=0.10, range [0.25 0.9]); and VISUAL COMPLEXITY (M=65.37, SD=6.35, range [44.84 82.2]), measured as the mean perimetric complexity of the component letters, where perimetric complexity of a letter is defined as the square of the length of the perimeter divided by the total ink area (Pelli, Burns, Farell, & Moore-Page, 2006 – see Figure 1). A correction for multiple comparisons using the False Discovery Rate (FDR) method was applied (Benjamini & Hochberg, 1995; Benjamini & Yekutieli, 2001; Groppe, Urbach, & Kutas, 2011).

RESULTS[4]

The partial correlations for each time slice and electrode are shown in Figure 2. The most significant correlations ($p < .01$, FDR corrected) are color-coded to show the direction and the strength of the correlation. The remaining significant correlations ($p < .05$, FDR corrected) are shown in grey in order to simply indicate that a significant correlation was present between a given variable and the voltage values obtained at a given electrode site at a given time. Plotting the results in this way enables an immediate appreciation of the timing and spatial distribution of the most robust effects among the variables we chose to analyze.

Figure 3 shows example waveforms from the experiment, obtained by averaging voltages obtained for the bottom 25% and the top 25% of the 960 values of the seven variables at the electrode sites selected to best illustrate the effects of each variable. Figure 3 is presented for illustrative purposes only, since the effects of each individual variable are contaminated by the influence of uncontrolled variables in this figure. Figure 2 provides the key results of the present study, and we will now summarize the findings shown in this figure.

The overall pattern of ERP effects shown in Figure 2 can be approximately divided into 5 phases:

1) 30-50 ms. Here we see an initial burst in the effects of visual complexity, and some early effects of consonant-vowel proportion, as well as more isolated effects of concreteness and word frequency.

2) 100-150 ms. Here we see an initial burst in the effects of word length (number of letters), accompanied by effects of word frequency in posterior electrode sites, as well as effects of consonant-vowel proportion. Effects of visual complexity become stronger and more widely distributed in this time-window.

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[3]Twenty different participants were asked to rate the 960 words tested in the present study on a 7- point Likert scale (7 = very concrete; 1 = very abstract). Participants were encouraged to use the full range of values. The obtained ratings were found to correlate highly with the concreteness ratings published by Brysbaert, Warriner, and Kuperman (2014), for the 931 words common to both studies ($r=0.90$, $p<0.001$).

[4]Data can be downloaded at https://osf.io/72b89/

3) 180-280 ms. Here we see widespread effects of word length, and lagging behind these we can see an increase in the effects of word frequency in posterior electrode sites, and the emergence of effects of bigram frequency in frontal and central electrodes. Visual complexity continues to have a widespread influence on ERPs in this time-window.

4) 280-380 ms. Here we see widespread effects of concreteness accompanied by effects of word frequency in frontal electrode sites that are opposite in polarity to the earlier posterior effects. There are also relatively widespread influences of orthographic distance and consonant-vowel proportion in this time-window, and a continuing effect of visual complexity.

5) 380-500 ms. In this final window we can see widespread effects of word frequency accompanied by effects of word length in posterior electrode sites, as well as a continuing but diminishing influence of concreteness, orthographic distance, bigram frequency, and consonant-vowel proportion.

In order to provide a more detailed appreciation of the scalp distribution of the different effects, Figure 4 shows the topographic distribution of the partial correlation coefficients of each variable of interest in these five time-windows.

Finally, we also examined ERP activities prior to word onset in the [-100 ms - 0 ms] baseline time-window, and from 500 ms up to 900 ms post-word onset. Prior to word onset there were only two significant ERP activities, which were driven by differences in number of letters ($p < .05$) at two different time points and two different electrodes. Most of the effects seen from 500 ms to 900 ms post-word onset were driven by word frequency, which continued to have a strong impact on ERPs. Consonant-vowel proportion also continued to have an influence up to about 600 ms post-word onset, and there were some smaller more isolated effects of orthographic distance and number of letters.

Table 1 provides the partial correlation matrix for the seven variables examined in the present study, and Table 2 provides the partial correlations between each of these variables and mean lexical decision RT extracted from the English Lexicon Project (ELP) database (Balota et al., 2007). In Table 1 it is interesting to note the correlations between the new variables that we have introduced in the present study (visual complexity, consonant-vowel proportion) and the other variables. These correlations might help explain some of the divergences in the pattern of ERP effects reported here with respect to prior studies.

In Table 2 we can see that word frequency has by far the strongest correlation with lexical decision RTs, followed by length in letters. What is more interesting is the relatively strong correlation between consonant-vowel proportion and mean RT that can be seen in Table 2, plus the significant positive correlation between bigram frequency and consonant-vowel proportion shown in Table 1. The latter correlation reflects that fact that the most frequent bigrams in English are composed of consonants. Thus, within the list of the 100 most frequent English bigrams found in Google books, 6 are composed of two vowels and 19 are composed of two consonants (Norvig, 2013). These two correlations point to a possible explanation for the relative fragility of effects of bigram frequency, as confirmed in the present ERP data and to be discussed below. Finally, it should be noted that visual complexity did not have a significant influence on RT. Future work will examine how the visual complexity of a word's component letters can be combined with factors such as letter visibility and the information carried by each letter (Stevens & Grainger, 2003) in order to predict word identification times.

DISCUSSION

Item-level data obtained in a large-scale ERP lexical decision experiment were analyzed in order to reveal the time-course of orthographic, lexical, and semantic influences during the processing of printed word stimuli. Crucially, effects of linguistic variables were compared with the effects of a visual variable, visual complexity, analyzed for the first time in an ERP study of visual word recognition. Although temporally and spatially isolated effects of several variables arose prior to 100 ms post-word onset, only two variables had more widespread effects - visual complexity and consonant-vowel proportion. The timing of the early effects of visual complexity provides a baseline against which the effects of linguistic variables can be better evaluated. It suggests that caution should be exercised when interpreting the isolated effects of concreteness and word frequency seen in roughly the same time-window. It further suggests that the more widespread effects of consonant-vowel proportion seen in the same epoch could well be driven by visual differences between consonants and vowels that are not captured by our measure of visual complexity.

Effects of word length (number of letters) emerged around 100 ms post-word onset, in line with prior reports of length effects emerging in a similar time-window (e.g., Amsel, 2011; Hauk, Davis, et al., 2006; Hauk et al., 2009). Rapidly after the onset of effects of word length we saw an influence of word frequency in posterior electrode sites. Word frequency effects gradually become stronger and extended to parietal electrode sites between 200 and 300 ms, and became even more widespread between 400 and 500 ms. The effect of word frequency seen between 120 and 160 ms post-stimulus onset is in line with the estimated onset of frequency effects reported in prior studies (e.g., Chen, Davis, Pulvermüller, & Hauk, 2015; Hauk et al., 2006; Strijkers, Bertrand, & Grainger, 2015).

Effects of orthographic distance (OLD20) started to emerge around 280 ms. The observed pattern is in line with prior investigations manipulating the number of single-letter substitution neighbors (e.g., Holcomb, Grainger, & O'Rourke, 2002; Laszlo & Federmeier, 2011). According to Holcomb et al. (2002), orthographic overlap with other words results in increased negativity in the ERP waveforms because of the greater overall activity in lexical representations. The fact that words with a greater proportion of consonants generated more negative ERPs suggests that this effect might be akin to effects of orthographic neighborhood, with more consonants leading to more activity in whole-word representations (Carreiras, Duñabetia, & Molinaro, 2009).[5] In a similar vein, the very limited effects of bigram frequency took the form of negative correlations with ERP voltage, such that the greater the bigram frequency of a word the more negative the voltage. The fact that we found no evidence for an early effect of bigram frequency, somewhat in contradiction with

[5]Consonant-vowel proportion correlates with number of syllables, a factor known to influence visual word recognition (e.g., Chétail, 2014). However, entering this variable into the partial correlation analyses revealed a much reduced impact on ERPs compared with consonant-vowel proportion.

prior studies (Hauk, Davis, et al., 2006; Hauk, Patterson, Woolams, Watling, Pulvermüller, & Rogers, 2006; Laszlo & Federmeier, 2014), could be due to the n-gram frequency effects reported in prior research being mainly driven by effects of consonant-vowel proportion.

Contrary to a number of prior studies, we found no evidence for early effects of a semantic variable (concreteness). Three studies in particular (Amsel, Urbach, & Kutas, 2013; Chen et al., 2015; Hauk, Coutout, Holden, & Chen, 2012) converge on an estimate of 160 ms for the emergence of semantic influences in the EEG/MEG signal. This estimate was obtained from ERP effects in a living/nonliving categorization task (Amsel et al., 2013; Hauk et al., 2012) and from regression analyses of the effects of imageability/concreteness on EEG/MEG responses (Chen et al., 2015). Chen et al. also reported that the effects of imageability / concreteness were stronger in a silent reading task than in the lexical decision task. More generally, the task modulation of early orthographic, lexical, and semantic effects reported in the Chen et al. (2015) study, points to a key role for proactive top-down mechanisms that modify stimulus-driven processing (see also Strijkers et al., 2015, for task modulation of word frequency effects). In a go/no-go living/nonliving categorization task, for example, pre-activation of the semantic features associated with the target category would enable these same features to reach criterion levels of activation faster upon stimulus presentation compared with presentation of the same word in the lexical decision task (see Laszlo & Federmeier, 2014, for a similar proposal). This, however, cannot account for the early effect of imageability/concreteness found in a silent reading task by Chen et al. (2015), and in this respect, the timing of effects of concreteness in the present study is more in line with the effects of semantic variables (including concreteness) emerging around 300 ms post-stimulus onset in Laszlo and Federmeier's (2014) regression analysis, and in line with the results of factorial manipulations of abstract vs. concrete words showing effects on the N400 component (e.g., Barber, Otten, Kousta, & Vigliocco, 2013; West & Holcomb, 2000).

Overall, the timing of the effects of the different variables examined in this study is suggestive of a fast initial feed-forward sweep of neural activity cascading through visual, orthographic, and lexical representations. This feed-forward activity would represent a fragile initial state of the network prior to stabilization through feedback (Grainger & Holcomb, 2009). As pointed out by Strijkers et al. (2015), this reactive feedback needs to be complemented with proactive mechanisms that enable preparatory activity prior to stimulus presentation. The combination of reactive and proactive top-down influences is likely to be at least partly responsible for the discrepancies in the timing estimates of component processes in visual word recognition obtained from ERP data, with some effects only being visible following feedback consolidation, and some effects being particularly sensitive to task-related preparatory mechanisms. Finally, the results of the present study plead for the inclusion of measures of visual influences on the ERP signal when evaluating effects of linguistic variables. It will also be important to examine the extent to which visual influences, as reflected in effects of visual complexity, for example, are sensitive to the nature of the task being performed. Another useful manipulation for future research would be to present stimuli in both lowercase and uppercase formats in order to provide further leverage with respect to separating the visual from the linguistic in printed word perception.

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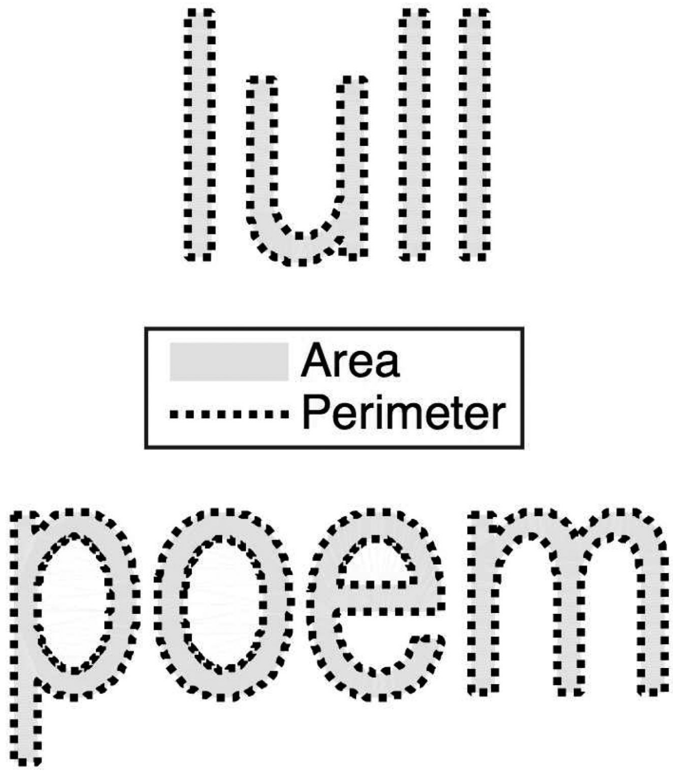

Figure 1.
Visual complexity of printed words measured using Pelli et al.'s (2006) perimetric complexity as follows: (i) images of words were digitally generated – here the words “lull” and “poem” in lowercase Arial font; (ii) these images were then processed to extract the perimeter of individual letters (dashed lines) and the corresponding area inside each perimeter (grey patches); (iii) for each letter the complexity was computed as the square of the sum of the inside and outside perimeters divided by the area; (iv) finally, the word's visual complexity was computed as the average complexity of its component letters (for word stimuli, Pelli et al. used the sum, which confounds complexity with orthographic length). The word “lull” has the lowest complexity (44.8) and “poem” the highest (82.2).

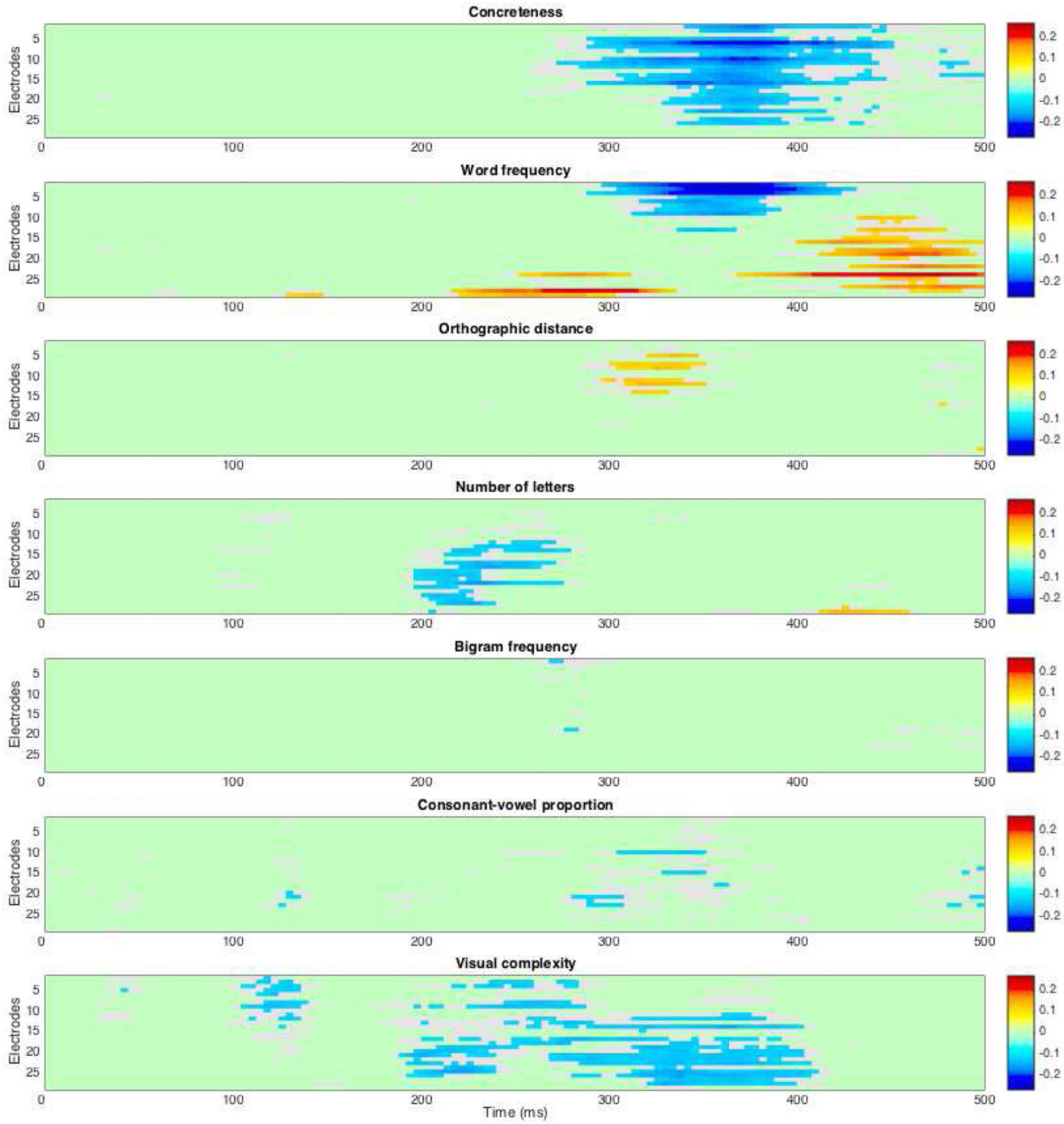

Figure 2.

Partial correlations for the seven variables of interest. Correlations represent the linear relation between ERP voltage and a given variable at each electrode and time slice, while partially out effects of the other variables. Color-coded coefficients (r) are provided for all correlations for which p < .01 (FDR corrected), and other significant correlations (p < .05) are shown in grey. The 29 electrode sites are aligned vertically with frontal sites at the top and occipital sites at the bottom.

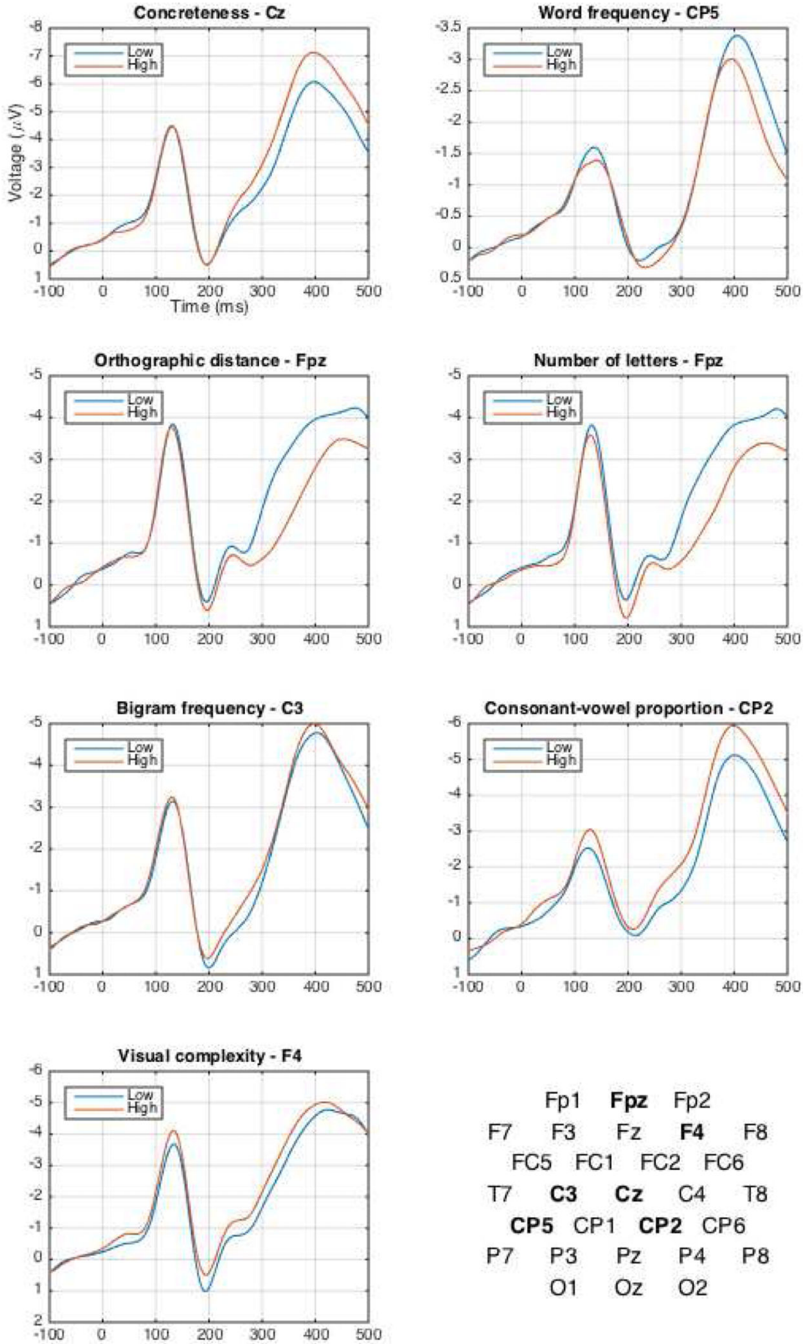

Figure 3.

Grand average waveforms obtained from the bottom 25% and top 25% values of each variable of interest (bottom 25% in blue, top 25% in red), for a representative electrode site selected for each variable. The positions of the selected electrodes are shown in bold in the bottom right panel (F: frontal; O: occipital; odd numbers: left hemisphere).

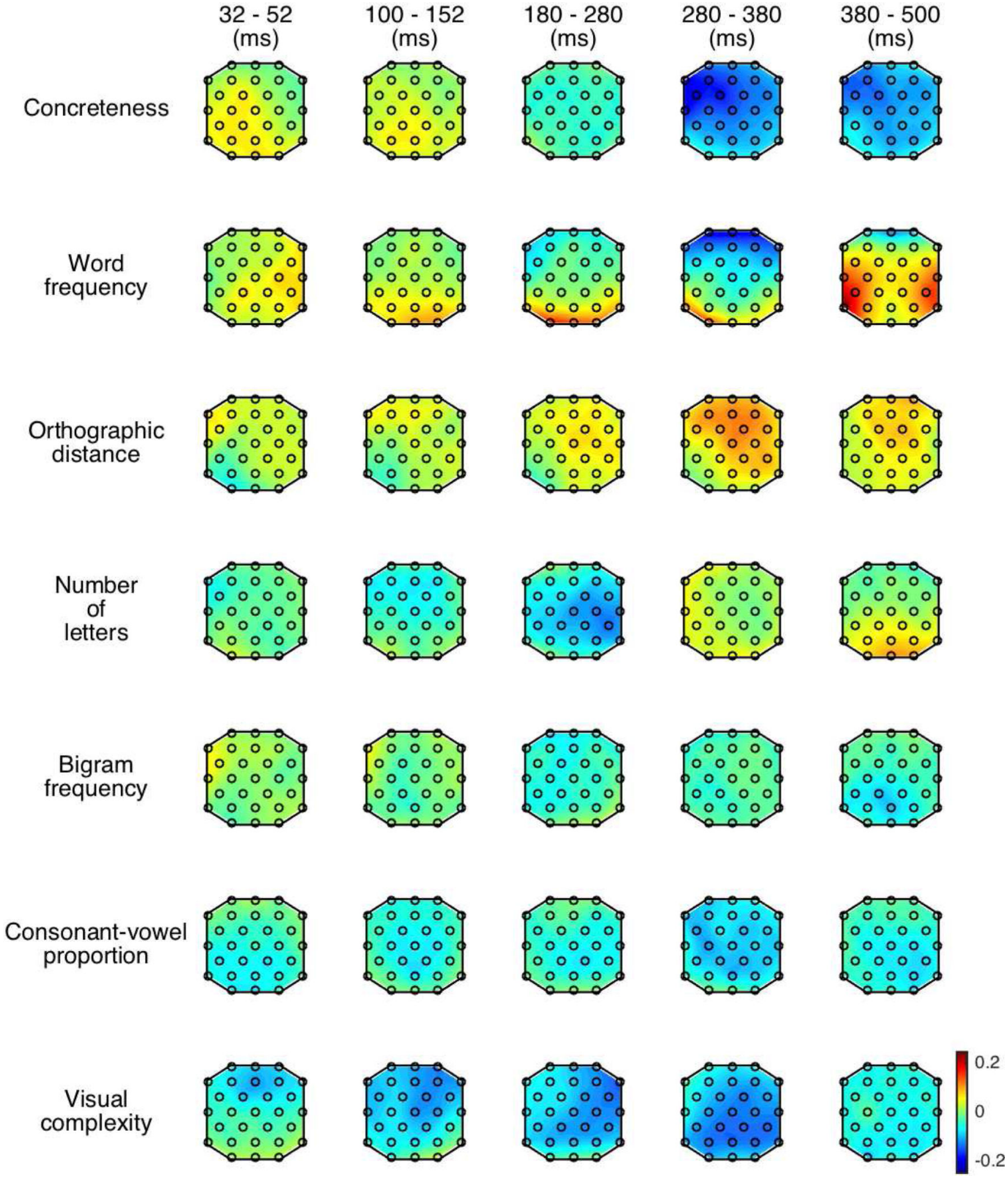

Figure 4.

Topographic maps of effects of each variable of interest in five time-windows. The color scale indicates partial correlation coefficients (r values) for each variable with the average voltage values in each time-window, calculated at each electrode site and smoothed across the scalp (see Figure 3 for the electrode montage).

Table 1

Partial correlations between the 7 variables of interest.

	CONC	FREQ	OLD	#LET	MBF	CVP	COMP
CONC	1.00						
FREQ	−0.17 (***)	1.00					
OLD	−0.02	−0.24 (***)	1.00				
#LET	−0.11 (***)	0.11 (***)	0.75 (***)	1.00			
MBF	0.04 (*)	0.08 (**)	−0.32 (***)	0.35 (***)	1.00		
CVP	0.09 (**)	−0.03 (*)	−0.06 (*)	−0.06 (*)	0.12 (***)	1.00	
COMP	−0.02	0.04 (*)	0.06 (*)	−0.12 (***)	−0.03 (*)	−0.10 (**)	1.00

Stars indicate the level of significance (*<.05; **<.01; ***<.001).

CONC: concreteness; FREQ: Frequency; OLD: Orthographic Levensthein Distance; #LET: number of letters; MBF: mean bigram frequency; CVP: consonant/vowel proportion; COMP: visual complexity.

Table 2

Partial correlations between lexical decision mean RTs (extracted from the ELP database: Balota et al., 2007) and the 7 variables of interest. RTs were log10 transformed, and RTs exceeding two standard deviations from the mean were removed, leaving 916 data points for the analysis.

	CONC	**FREQ**	**OLD**	**#LET**	**MBF**	**CVP**	**COMP**
RT	−0.07 (0.03)	−0.59 (<0.01)	0.08 (0.02)	0.09 (<0.01)	0.06 (0.09)	−0.08 (0.01)	−0.06 (0.10)

P-values are shown in parentheses.

CONC: concreteness; FREQ: Frequency; OLD: Orthographic Levensthein Distance; #LET: number of letters; MBF: mean bigram frequency; CVP: consonant-vowel proportion; COMP: visual complexity.