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Semantic Richness and the Activation of Concepts in Semantic Memory: Evidence from Event-Related Potentials

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Abstract

Semantic richness refers to the amount of semantic information associated with a concept. Reaction-time (RT) studies have shown that words referring to rich concepts elicit faster responses than those referring to impoverished ones, suggesting that richer concepts are activated more quickly. In a recent functional neuroimaging study, richer concepts evoked less neural activity, which was interpreted as faster activation. The interpretations of these findings appear to conflict with event-related potential (ERP) studies showing no evidence that speed of concept activation is influenced by typical semantic variables. Resolution of this apparent contradiction is important because the interpretation of 40 years of semantic-memory RT studies depends on whether factors such as semantic richness influence the duration of initial concept activation or later decision and response processes. Consistent with previous studies of the effects of semantic factors on ERP, the present study shows that richness influences the magnitude, but not the latency, of the P2 and N400 ERP components (which are early relative to behavioral responses), suggesting that effects of richness on RT reflect temporal effects on downstream decision or response mechanisms rather than on upstream concept activation.

Keywords

Concreteness; Event-Related Potentials; N400; Semantic Memory; Semantic Richness

1. Introduction

The term *semantic richness* refers to the amount of semantic information contained in or associated with a concept in semantic memory. Richness has recently emerged as an important factor in semantic memory research, as this factor has been shown to mediate the speed and/or accuracy of behavioral responses in a variety of tasks, such as lexical decision, categorization, naming, etc. (Dunabeitia et al., 2008; Grondin, Lupker, & McRae, 2009;

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Pexman, Holyk, & Monfils, 2003; Pexman, Hino, & Lupker, 2002). The major finding emerging from these studies is that greater semantic richness facilitates performance. This result is intriguing because it implies that more semantic information leads to faster and/or more accurate performance rather than burdening the system and reducing performance.

Simulations suggest that when a semantically rich concept is inputted into a parallel-distributed processing (PDP) network, the network may settle into a stable state more quickly than occurs when a more impoverished concept is inputted (Plaut & Shallice, 1993). Based on this notion, Pexman et al. (2007) predicted that rich concepts would evoke less neural activity than more impoverished concepts. Their functional magnetic resonance imaging (fMRI) study confirmed this prediction, with a number of brain areas exhibiting less activation when processing rich concepts relative to more impoverished concepts, and with no significant effects in the opposite direction.

The findings of Pexman et al. (2007) pose a quandary because the notion that semantic richness influences the speed with which a semantic representation is activated seems to contradict findings from event-related potential (ERP) studies of semantic memory. Most such ERP research has focused on the N400, a negative deflection peaking about 400 milliseconds after stimulus onset which reflects both context-dependent and context-independent semantic factors (Kounios, 1996; Kutas & Hillyard, 1980). In a variety of verification tasks, a number of semantic manipulations, such as concreteness, relatedness, and hierarchical level, have been shown to influence the amplitude of the N400, but have little or no effect on its latency (Kounios, 1996). Furthermore, it is often the case that the effects of semantic factors on behavioral response times are not accompanied by parallel effects on either N400 latency or amplitude (Kounios & Holcomb, 1992), though nonsemantic factors such as stimulus quality can delay N400 peak latency (Holcomb, 1993). Based on such findings, Kounios (1996) argued that the initial activation of semantic representations does not vary much in duration; effects of semantic factors on reaction times are primarily due to the influence of these factors on relatively late processes, such as decision and response-selection mechanisms, rather than on early concept-activation processes.

In sum, Pexman et al. (2007) assumed that the amount of time required to activate a semantic representation is influenced by semantic factors, such as richness. In contrast, the ERP literature suggests that upstream activation processes vary little in duration; the temporal lability of response times in semantic tasks is primarily due to effects on downstream processes. The conclusions of Pexman et al. therefore contradict the general pattern of findings from the ERP literature. This contradiction is worth resolving because the interpretation of 40 years of reaction-time studies of semantic memory since the seminal studies of Collins and Quillian (1969) and Meyer (1970; see Chang, 1980, and Holyoak, 2007, for reviews of these early studies) rests on how such RT effects should be interpreted, whether as effects on upstream activation processes that directly reflect properties of the activated representations or as effects on downstream decision processes (Holyoak, 2007; Kounios, 1996).

The present high-density ERP study aimed to resolve this contradiction by examining the effects of semantic richness on the amplitude and latency of the P2 and N400 components. In order to explain the design and analysis, we first review relevant aspects of the Pexman et al. (2007) study.

First, as Pexman et al. (2007) pointed out, there are several ways in which to quantify semantic richness. In previous articles such as Pexman et al. (2002; 2003), they quantified this variable by manipulating the number of features (NoF) based on McRae and colleagues' semantic feature production norms (McRae, Cree, Seidenberg, & McNorgan, 2005; McRae, de Sa, & Seidenberg, 1997). In contrast, Pexman et al. (2007) used association norms (Nelson et al.,

1998) to compute the number of different first associations - across participants - produced to each word, and took this to reflect the number of close associations for each concept. However, this measure is potentially problematic because it could instead reflect the variability of associations across participants. For example, if the strongest association to a rich concept's representation differs greatly across participants, then this measure could yield an inaccurate estimate of the concept's richness, that is, it may provide little or misleading information regarding the number of associations for an individual person. The present study used what we propose to be a less-biased measure of the amount of semantic content associated with each concept, namely, a within-subject estimate of the number of features associated with each concept.

Second, Pexman et al. (2007) predicted that rich concepts evoke less neural activity than impoverished concepts. This prediction was based on simulations suggesting that a PDP network can settle into a stable state more quickly when processing a rich concept (Plaut & Shallice, 1993). However, it is not clear why the *speed* of network stabilization in a computer simulation necessarily speaks to the issue of the *magnitude* of signal change as measured with fMRI. They did not present any relevant temporal information.¹ One possibility that Pexman et al. did not explicitly mention is that, all things being equal, a neural process that is shorter in duration will result in less temporal summation of an fMRI BOLD response, thereby yielding less activation integrated over time. In this case, however, the assumption of "all things being equal" has no prior theoretical or empirical justification. Consequently, the present study utilized high-density ERPs to examine the time-course of processing as this technique is better suited for answering such questions. Though the ERP technique does not have the same degree of spatial resolution as fMRI, it has superior temporal resolution, thereby providing enhanced capability for assessing dynamic properties of semantic processing (Kounios, 1996).

Third, Pexman et al. (2007) used a semantic task that may not have been optimal for the purpose of assessing semantic richness effects. Their task required participants to categorize each stimulus word as representing something that either is, or is not, consumable (i.e., edible or potable). Their analyses focused only on concepts representing consumable items. This task may have biased the processing of the stimulus concepts toward semantic features relevant to making judgments of consumability. The number-of-associates measure used to select words high and low in semantic richness has an unknown relationship to the amount of information in a concept relevant to the consumability judgment. The present study sought to enhance the generality of its conclusions by using a task that did not require participants to make decisions about the stimulus words during concept activation. Specifically, on each trial, a subject viewed a pair of words presented in sequence with a stimulus-onset asynchrony of 2 sec. Their task was to judge the relatedness of the words. During the interstimulus interval, participants held the briefly-flashed first word in working memory while awaiting the second word. This study focused on brain activity in response to only the first word of each pair, crucially, before the second word was presented. Therefore, no response was required or allowed during this critical interval of EEG recording. Because this paradigm required participants to make relatedness judgments for each pair of words, and because the design of the experiment did not cue them to expect that the second word would come from any particular category, participants were encouraged to process the first word deeply but without any particular bias as to the type of semantic information that would be required by the judgment.

¹The behavioral results of Pexman et al. showed a small (i.e., 18 ms), but significant, reaction time advantage for richer concepts. There was, however, a small (.84%) but nonsignificant accuracy difference in the opposite direction, suggesting the possibility that the small reaction time effect may have been at least partly driven by a speed-accuracy tradeoff between the rich and impoverished conditions rather than solely reflecting a processing advantage for rich concepts. Either way, the present study is consistent with previous findings (see Kounios, 1996) in suggesting that the locus of such reaction-time effects is a downstream decision process and not upstream semantic activation.

Additionally, to further enhance the generalizability of our results, the stimuli were drawn from a number of semantic categories, rather than from just the category of consumables.

This study also included abstract nouns as critical stimuli, in addition to semantically rich (high number of features, or *HNF*) and impoverished (low number of features, or *LNF*) concrete nouns. Abstract words have little or no featural content compared to concrete words (Holcomb et al., 1999; Kounios & Holcomb, 1994). By including abstract words, we were able to examine three, rather than just two, points on the continuum of semantic richness, with richness defined in terms of the amount of featural content.

In sum, the present study used ERPs to test the hypotheses that greater semantic richness affects (a) the magnitude of semantic processing, as reflected by effects on ERP amplitudes, and (b) the speed of semantic processing, as reflected by effects on the peak latencies of the P2 and N400 components, which are clearly identifiable “landmarks” during the time-course of processing.

2. Results

Behavioral Data

Mean reaction times for correct relatedness judgments were 626 ms ($SD = 311$) for HNF, 653 ms ($SD = 317$) for LNF, and 734 ms ($SD = 358$) for ABS, which differed significantly ($F[2,52] = 52.86, p < .001$). Pairwise two-tailed t -tests showed that the mean reaction time for each condition differed significantly from each of the other two conditions ($4.37 < t[26] < 8.17, p < .001$).

Mean accuracies for the relatedness judgments were 91.8% ($SD = 10.5$) for HNF, 86.5% ($SD = 9.0$) for LNF, and 84.0% ($SD = 8.9$) for ABS, which also differed significantly ($F[2,52] = 23.39, p < .001$). [Participants timed out without responding by the deadline on 2.5% of the trials.] Pairwise two-tailed t -tests showed that the mean accuracy for each condition differed significantly from the other two conditions ($2.95 < t[26] < 5.74, p < .0075$).

It is important to note that these results, which are reported here for the sake of completeness, are not directly relevant to the richness manipulation that is central to this experiment. Lexical and semantic variables associated with the second words were not strictly equated across conditions, and reaction times were measured relative to second-word onset. These results therefore provide little, if any, information regarding the activation of the first concepts, which were the targets of the ERP analyses.

ERP Data

Overview—The first set of ERP analyses focused on amplitude differences among the stimulus conditions for three time-windows: (a) the 200-300 ms (P2) epoch, (b) the 300-500 ms (N400) epoch, and (c) the 500-800 ms epoch containing the Late Positive Component (LPC). These analyses were designed to detect differences in magnitude of brain activation. They show that richness does influence the magnitude of neural activity early during the time-course of processing. The second set of analyses examined possible component timing effects by comparing the latencies of the amplitude peaks for the P2 and N400 components. [The LPC does not have a clearly identifiable peak.] These analyses show no significant effects of richness on the P2 or N400 latencies.

Figure 1 shows the grand-average ERP waves (for a subset of the electrode sites used) corresponding to participants' neuroelectric responses to the first word of each pair. The P2 component peaks at approximately 240 ms post-stimulus and the N400 component at approximately 400 ms; a subsequent Late Positive Component follows the N400.

ERP amplitudes—Results of the amplitude ANOVAs are presented in Table 2. For the HNF versus LNF comparison, there was a significant main effect of richness and a richness by dorsal-ventral interaction in the 200-300 and 500-800 ms time-windows. These effects were marginally significant in the 300-500 ms time-window. For the ABS versus LNF comparison, the 300-500 ms time-window yielded a significant main effect of richness and a marginally significant anterior-posterior by hemisphere by richness interaction. For the 500-800 ms time-window, this interaction was significant and the main effect of richness was marginally significant. The ABS versus HNF comparison yielded only one marginally significant effect, a dorsal-ventral by richness interaction.

Figure 2 shows topographic maps of the amplitude differences (HNF-LNF, LNF-ABS, and HNF-ABS) for the 3 time-windows. These maps display the direction, magnitude, and spatial distribution of the voltage differences between conditions. For the sake of completeness, maps are shown even for comparisons between conditions that did not achieve statistical significance (see Table 2). A detailed description of these topographic differences is beyond the scope of this article. For present purposes, two important observations should be noted. First, semantic richness did significantly influence voltage magnitudes. In 2 of the 3 epochs, HNF differed from LNF and LNF differed from ABS. HNF did not differ from ABS in the 300-500 or 500-800 ms time-windows, and exhibited only a marginally significant difference in the 200-300 ms time-window. Second, though the direction of the voltage differences was not completely uniform in any of the maps, generally, the direction of the differences was, from positive to negative: (a) 200-300 ms: HNF > ABS > LNF; (b) 300-500 ms: ABS > HNF > LNF; (c) 500-800 ms: HNF > ABS > LNF. As a general principle of ERP interpretation, in any given situation it is not clear whether positive scalp voltages indicate greater neural activity and negative voltages indicate less neural activity, or vice versa. However, the notion of semantic richness predicts either an ABS > LNF > HNF or an HNF > LNF > ABS ordering, which was not obtained in any time-window. Consequently, at the very least, these results do not support the notion of a monotonic decrease (or increase) in neural activity with increasing semantic richness. However, they do demonstrate that richness does influence the magnitude of neural activity.

ERP component latencies—ANOVAs yielded no evidence of differences in peak latency for the P2 component comparing ABS with either HNF or LNF, though the ANOVA comparing P2 peak latencies for HNF and LNF yielded the following marginally significant interactions: (a) anterior-posterior by richness ($F[3,78] = 2.68, p < .06$); (b) hemisphere by richness ($F[1,26] = 3.50, p < .08$), (c) anterior-posterior by hemisphere by richness ($F[3,78] = 2.25, p < .09$). To determine whether these marginally significant interactions indicate the possibility that HNF nouns are processed more quickly than LNF nouns, and to determine the topographic distribution of this effect, *t*-scores were calculated for the HNF/LNF comparisons across electrodes and were plotted as a topographic map (not shown) as a follow-up to this ANOVA. The only scalp region with electrodes yielding an effect of $p < .05$ (two-tailed) was over left posterior cortex, near the junction of parietal, temporal, and occipital cortices. However, this effect was not in the direction hypothesized by Pexman et al. (2007); in the present case, the trend was for the P2 peak latency to be slightly *later* for HNF words than for LNF words. For example, at the P7 electrode, peak latency for HNF was 244 ms and 221 ms for LNF.

For N400 peak latency, the only ANOVA to yield a significant effect compared ABS and LNF (dorsal-ventral by richness interaction; $F[1,26] = 5.15, p = .032$). Follow-up electrode-wise *t*-tests of the main effect of richness yielded no *t*-score corresponding to $p < .05$ (two-tailed). In addition, there was a marginally significant anterior-posterior by dorsal-ventral by richness interaction for the comparison of HNF versus LNF ($F[3,78] = 2.60, p = .058$). Again, follow-up *t*-tests of the main effect of richness yielded no *t*-score corresponding to $p < .05$ (two-tailed). The lack of significant electrode-wise *t*-scores indicates that these significant and marginally

significant ANOVA results were due to different topographic distributions of peak latencies rather than magnitude differences.

Table 3 shows the mean P2 and N400 peak latencies (averaged across all electrode sites) for ABS, LNF, and HNF words. For the P2 peak latencies, the range across the stimulus conditions was 3 ms. For the N400 peak latencies, the range across conditions was 7 ms. In sum, the above analyses provide no evidence consistent with the notion that a distributed semantic network settles more quickly for rich concepts compared to impoverished ones.

3. Discussion

This study examined the effects of semantic richness on the magnitude and speed of neural activity associated with concept activation. Using a carefully balanced stimulus set, an experimental design optimized for examining semantic activation relatively uncontaminated by decision processes, and a dependent measure (ERPs) capable of detecting both magnitude and latency effects, neural responses to words that were of very low (ABS), moderately low (LNF), and high (HNF) semantic richness were compared. Several important findings emerged.

First, comparisons of ERP voltages in 3 time-windows showed significant effects of semantic richness, though the effects were relatively small and were not significant for ABS/HNF comparisons. These results support the notion that semantic richness does influence magnitude of concept activation in semantic memory, although the small size of the effects raises the possibility that richness may not be one of the most important factors influencing concept activation.

Second, there were no significant effects of richness on the peak latencies of the P2 and N400 components. This finding does not support the notion, suggested by Pexman et al. (2007), that richness influences a concept's activation latency, or, more specifically, the speed with which a distributed semantic network settles into a particular pattern of activation. It should be noted that this inference does not depend on a theory of the specific processes manifested as these components. The P2 and N400 were used here primarily as clearly identifiable temporal landmarks during the time-course of processing, though, irrespective of its specific function, the N400 in particular has been shown in numerous studies to be exquisitely sensitive to semantic variables.

Third, the ERP voltages for the three stimulus conditions did not support the notion of a monotonic ordering of neural activity according to semantic richness (i.e., either $ABS > LNF > HNF$, or $HNF > LNF > ABS$). This suggests that either semantic richness has a non-monotonic effect on concept activation, or that richness, as isolated in this experiment, may be confounded with some other factor or factors whose neural correlates have not yet been isolated and identified.

One possibility is that characteristics of individual concepts do not completely specify the dynamics of semantic activation, even when these concepts are presented without any overt context, but that the relationship between each concept and other concepts in semantic memory must be considered. For example, Grondin et al. (2009) distinguished between the number of features that a concept shares with other concepts and the number of features that are distinctive to it (and thus are not possessed by many other concepts). They showed that the number of shared features more strongly influences reaction times in lexical and semantic decision tasks. They also showed that certain classes of features (e.g., visual form and surface features) have stronger effects on reaction time than do others, at least in terms of the number of features of each class that are possessed by a concept. These findings suggest that future investigations should not be confined to individual concepts' lexical variables and externally provided context

because the structure of semantic memory may provide its own internal context that influences the activation of isolated concepts.

A surprising finding was that LNF, but not HNF words, elicited a larger N400 compared to ABS words. Previous research (e.g., Holcomb et al., 1999; Kounios & Holcomb, 1994) has shown that concrete words elicit a larger N400 than abstract words. The fact that the present study demonstrated this effect only for LNF words suggests that previous studies that examined concreteness effects may have confounded concreteness with semantic richness. These results therefore suggest a reexamination of concreteness effects using tighter stimulus controls, including semantic richness.

Finally, the present results provide additional support for the observation that the semantic manipulations typically used in experimental paradigms have little or no effect on the duration of upstream semantic activation, but that reaction-time effects of these manipulations result instead from their influence on downstream decision and response processes (Kounios, 1996). Specifically, semantic richness evidently influences the magnitude, but not the latency, of neural activity associated with upstream concept activation. Contrary to the conclusions of Pexman et al. (2007), the results of the present study are consistent with recent findings by Grondin et al. (2009) who found that concept activation was not influenced by richness in connectionist simulations. In sum, the present study and the study of Grondin et al. support the conclusion that richness influences semantic and lexical decision processes rather than the activation of word meaning per se.

4. Experimental Procedure

Subjects

Twenty-seven right-handed, native English-speaking participants took part in a 2-hour session after giving informed written consent. The study was approved by the Drexel University Institutional Review Board.

Stimuli

HNF and LNF words (65 each) were drawn from Experiment 1 of Grondin et al. (2009) and were based on the semantic feature production norms of McRae et al. (2005). HNF and LNF words were balanced for 12 lexical and semantic variables (for details, see Grondin et al., 2009, Table 1, p. 4). Using these stimuli, Grondin et al. found a 30 ms advantage for HNF words in lexical decision, and a 29 ms advantage in a concreteness decision task. To these were added 65 abstract words which were equated to the HNF and LNF words for five lexical variables (see Table 1).

Procedure

Each trial began with an auditory tone and a “Get Ready” message displayed at the center of a computer monitor for 500 ms, followed by a “+” fixation mark displayed for 500 ms. The first word of each pair was then displayed for 250 ms, followed by a fixation mark for 1,750 ms. Then, the second word of the pair was displayed for 250 ms, followed by a fixation mark displayed for 2,000 ms. Participants were required to respond by button-press before the end of the latter 2,000-ms fixation interval. The participants' task was to judge whether or not the two words in each pair were semantically related and to indicate this by pressing 1 of 2 buttons on a computer mouse their right hand. This interval was followed by an “OK to blink” message displayed for 3,000 ms. The response deadline was included in order to encourage participants to semantically process the first word as soon as it was displayed, thereby enabling them to respond more quickly to the second word.

EEG acquisition

Continuous electroencephalograms (EEG) were recorded at 250 Hz (bandpass: .2-100 Hz) with MANSCAN RECORDER (www.manscaneeg.com) using 128 tin electrodes embedded in an elastic cap (digitally-linked mastoid reference), placed according to the extended International 10-20 System. Prior to averaging, eye-blinks were removed from the data with an adaptive filter constructed separately for each subject using EMSE 5.1 (www.sourcesignal.com). Bad channels were replaced with values interpolated based on neighboring channels.

ERP analyses

Trials with uncorrectable artifacts were deleted prior to averaging. ERPs were formed by separately averaging (a) HNF, (b) LNF, and (c) ABS word trials. These ERPs were computed from all non-artifact trials. Trials with response errors were not excluded from the analyses because the error rates were relatively low and because many of these errors were undoubtedly due to inaccurate processing of the second word and/or inaccurate relatedness judgments, rather than to inadequate processing of the first word. Therefore, little, if any, contamination was introduced by including all trials in the ERP analyses for the first words.

The averaging epoch was 2,200 ms, beginning with the 200-ms prestimulus interval (i.e., prior to the first word of each pair). Analyses focused on 3 epochs: 200-300, 300-500, and 500-800 ms after the onset of the first word.

Repeated-measures analyses of variance (ANOVA) were performed on ERP amplitude and peak-latency values using the Huynh-Feldt correction for nonsphericity where appropriate. Each ANOVA had an anterior-posterior factor (4 levels), a hemisphere factor (2 levels), a dorsal-ventral factor (2 levels), and a semantic richness factor (2 levels). Because an omnibus ANOVA including all three levels of semantic richness would not be sufficiently informative regarding the issues of primary concern, separate ANOVAs were computed for each contrast of 2 of the 3 levels of the Richness factor (i.e., HNF versus LNF, HNF versus ABS, and LNF versus ABS) for each of the 3 time-windows. The electrodes used in the ANOVAs were F1/2, F7/8, C1/2, T7/8, P1/2, P7/8, O1/2, and O9/10. Because this article is concerned with main effects of the richness factor and with interactions of the electrode factors with richness, only these results are reported here. Voltage values were not normalized because this procedure would have removed main effects of stimulus-type. Formally identical analyses focused on the latency of the peak positive amplitude for the 200-300 ms (P2) time window and on the latency of the peak negative amplitude for the 300-500 ms (N400) time window. These analyses were intended to examine the possibility of differential component timing for the 3 richness conditions.

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Figure 1.

Event-related potentials (ERPs) for high number of features (High NoF, red waves), low numbers of features (Low NoF, green waves), and Abstract concepts (blue waves) shown at representative electrode sites. For each graph, the *x*-axis represents time starting .2 sec before the onset of each word in a stimulus pair. The *y*-axis represents microvolts, with negative voltages plotted up on the *y*-axis according to ERP convention. Electrode sites at the front of the head are displayed at the top of the figure; sites on the right side of the head are displayed at the right side of the figure, etc. The P2 and N400 components are labeled at the central midline (CZ) electrode.

Figure 2.

Topographic ERP maps of the High-minus-Low, Low-minus-Abstract, and High-minus-Abstract differences in microvolts (rows) for the 200-300, 300-500, and 500-800 ms epochs (columns). Each map represents a view of the top of the head, with the nose at the top, the left ear at the left, etc. For each map, the red end of the scale reflects differences with positive voltage values and the blue end of the scale reflects differences with negative values. The middle 33% of the scale was grayed-out to visually highlight the upper and lower tertile of the distribution. Each red dot represents the location of an electrode. The interpolation between electrodes was provided by a spline-fitting procedure.

Table 1
Characteristics of Experiment 1 Stimuli

Variable	Low NoF		High NoF		Abstract	
	M	SE	M	SE	M	SE
Concreteness	615.0	5.7	634.0	3.4	-	-
Number of features (NoF)	9.0	0.2	15.7	0.3	-	-
ln(BNC) frequency	6.4	0.2	6.4	0.2	6.5	0.2
Familiarity	5.7	0.2	5.7	0.2	-	-
Number of letters	5.4	0.2	5.4	0.2	5.4	0.2
Number of phonemes	4.4	0.2	4.5	0.2	4.5	0.2
Number of syllables	1.6	0.1	1.7	0.1	1.8	0.1
Orth. neighborhood size (N)	4.6	0.8	4.4	0.7	4.7	0.7
Semantic density	156.9	20.1	155.3	11.3		
Number of creatures	18	-	21	-		
Number of fruits/vegetables	11	-	8	-		
Number of nonliving things	35	-	35	-		

Note. NoF = Number of Features, ln = the natural logarithm (log_e), BNC = British National Corpus

Table 2

Results of ERP amplitude analyses involving ANOVAs with a Richness factor (High versus Low, Abstract versus High, or Abstract versus Low), and Dorsal-Ventral (DV), Hemisphere (H), and Anterior-Posterior (AP) electrode factors. Results in boldface are significant at the $p < .05$ level; results in regular font are marginally significant ($.05 < p < .10$).

	200-300 ms	300-500 ms	500-800 ms
Hi versus Lo	Richness $F(1,26) = 5.92, p = .022$ DV X Richness $F(1,26) = 6.08, p = .021$	Richness $F(1,26) = 4.08, p = .054$ DV X Richness $F(1,26) = 3.18, p = .086$	Richness $F(1,26) = 5.16, p = .032$ DV X Richness $F(1,26) = 4.80, p = .038$
Abs versus Hi	DV X Richness $F(1,26) = 3.77, p = .063$	<i>n.s.</i>	<i>n.s.</i>
Abs versus Lo	<i>n.s.</i>	Richness $F(1,26) = 14.54, p = .001$ AP X Richness $F(3,78) = 2.52, p = .077$	Richness $F(1,26) = 3.63, p = .068$ AP X H X Richness $F(3,78) = 3.30, p = .029$

Table 3

Mean P2 and N400 peak latencies (in ms, with standard deviations in parentheses) averaged across all electrode sites for Abstract (ABS), low number of features (LNF), and high number of features (HNF) words.

	ABS	LNF	HNF
P2	242 (35)	239 (35)	241 (35)
N400	408 (67)	402 (61)	401 (66)