TITLE:

ERP and behavioral effects of semantic ambiguity in a lexical decision task

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Abstract

In the present study we examined electrophysiological and behavioral correlates of ambiguous word processing. In a lexical decision task, participants were presented with ambiguous words with unrelated meanings (i.e., homonyms; e.g., *bat*), ambiguous words with related meanings (i.e., polysemes; e.g., *newspaper*), and unambiguous words (e.g., *guitar*). Ambiguous words elicited larger N400 amplitudes than unambiguous words and showed an advantage in RTs. Importantly, no differences were found between homonyms and polysemes, on either N400 amplitudes or in RTs. These results suggest that ambiguous words, regardless of the relatedness between their meanings, benefit from enhanced semantic activation in comparison to unambiguous words during word recognition.

Keywords

Semantic ambiguity; ambiguity advantage; meanings relatedness; polysemy; homonymy; word recognition; ERP; N400

1. Introduction

Understanding how meaning is retrieved from printed words and how it is represented in the mind are two primary goals of word recognition research. A fruitful line of research has been devoted to elucidate how orthography and semantics interact during word recognition, and to examine which semantic variables play a role in this process. Among such variables, semantic ambiguity has been one of the most studied. Semantic ambiguity refers to a linguistic phenomenon in which an orthographic form is mapped to more than one meaning (e.g., the word *pupil*, which means both *a student* and *the opening in the iris of the eye*). Given this one-to-many relation between orthography and meaning, semantic ambiguity poses intriguing questions for word recognition research. One central issue is whether ambiguous words have one or multiple lexical/semantic representations. For instance, are both meanings of the word *pupil* (e.g., *student* and *part of the eye*) included in the same lexical/semantic representation, or are they listed in separate lexical/semantic representations? A further crucial question is how orthography and semantics interact during the recognition of ambiguous words. Do the meanings *student* and *part of the eye* compete during the recognition of the word *pupil*? Or rather, does having two meanings, and thus more semantic information, facilitate the recognition of such a word? The aim of the present study was to shed some light on these questions by examining the behavioral and electrophysiological correlates of ambiguous word processing.

Rubenstein, Garfield, and Millikan's (1970) were the first to address some of these issues. Its main finding was that ambiguous words were recognized faster than unambiguous ones in a lexical decision task (LDT; a task in which participants decide whether a string of letters is a real word or not). Since the pioneering work of

Rubenstein et al. (1970), there have been many reports of such a facilitation for ambiguous words in LDT (i.e., the *ambiguity advantage*) (e.g., Borowsky & Masson, 1996; Hino, Lupker, & Pexman, 2002; Hino & Lupker, 1996; Jastrzembski & Stanners, 1975; Jastrzembski, 1981; Kellas, Ferraro, & Simpson, 1988; Millis & Button, 1989; Pexman, Hino, & Lupker, 2004).

The ambiguity advantage appears to be a consistent effect in the literature (see, however, Rodd, Gaskell, & Marslen-Wilson, 2002). For this reason, it has had significant implications for models of word recognition, and has also received different explanations. Some accounts propose that ambiguity effects are located at the surface level of the representation of words (i.e., orthography/phonology), whereas others suggest that they are located at the semantic level of representation (see Armstrong & Plaut, 2016, for an overview). With respect to the former, it is worth mentioning the Parallel Distributed Processing (PDP) model of word recognition proposed by Kawamoto, Farrar, and Kello (1994). This model consists of two processing modules representing the orthography and semantics of words. The model was trained with pairs of activation patterns representing the form and meaning of the words. After the training phase, the authors assessed the performance of the network by presenting just the orthographic pattern of the words, observing that ambiguous words reached the criterion for a lexical decision faster than unambiguous words (i.e., the orthographic units of the model achieved their maximum level of activation faster when they were presented with an ambiguous word). To explain this behavior, the authors showed that the network tried to compensate for the inconsistent orthographic-to-semantic relation for ambiguous words (i.e., one orthographic form associated with multiple meanings) by strengthening the connection weights between their orthographic units. These stronger connection weights between orthographic units would serve to speed up the settling of the orthographic representation of ambiguous words, hence facilitating lexical decisions.

With respect to those accounts that have focused on semantics, it has been suggested that there would be an advantage for ambiguous words during word recognition because they elicit a larger amount of semantic activation (i.e., *semantic-based accounts*; e.g., Borowsky & Masson, 1996; Hino & Lupker, 1996). For instance, based on interactive activation principles, several authors have proposed that after the presentation of an orthographic input, the activation would flow bidirectionally between the orthographic and semantic levels (Balota, Ferraro & Connor, 1991; McClelland & Rumelhart, 1981). In addition, they assumed that a word would be recognized in a LDT when the activation of its orthographic representation reached a recognition threshold. With these assumptions in place, the explanation of the ambiguity advantage is straightforward: because ambiguous words have more than one semantic representation, they would cause a larger semantics-to-orthography feedback than unambiguous words, and thus would reach the orthographic recognition threshold faster. A similar account was provided by the PDP model of Borowsky and Masson (1996). In this model, words were represented as patterns of activation across orthographic, phonological and semantic processing units. Additionally, a word was thought to be recognized when the level of activation of the network reached a given threshold. The level of activation of the network indicated the distance from the current state of the network to the pattern of orthographic and semantic activation corresponding to a known word; that is, the higher the activation of the network, the lower the distance to a learned pattern. The simulation data showed interesting behavior when ambiguous words were presented to the model, because in those cases the meaning units of the network settled faster into a state in which the two meanings of the ambiguous word were partially activated. Since these blend states were similar to both learned semantic patterns of the word, ambiguous words elicited more semantic activation and reached the criterion for a lexical decision faster than unambiguous words.

It should be noted that according to semantic-based accounts, the ambiguity advantage is closely related to the so-called semantic richness effects reported in word recognition research. Work on semantic richness is devoted to examine to what extent the amount of semantic information of a word influences its recognition (Pexman, Hargreaves, Siakaluk, Bodner, & Pope, 2008; Pexman, Siakaluk, & Yap, 2013). Semantic richness effects in behavioral responses are quite homogeneous, in that words having more or richer semantic information (e.g., number of semantic features, number of semantic neighbors, or number of word associates) are associated with faster response latencies in a number of experimental tasks, such as LDT, naming and semantic categorization (Pexman et al., 2008). In addition, semantic richness effects have also been found in EEG studies. Particularly, the amount of semantic information a word contains seems to modulate the N400 component, a negative-going potential that is thought to reflect mainly semantic processing (see Kutas & Federmeier, 2011 for a review). For example, there is evidence, a) that concrete words elicit larger N400 amplitudes than abstract words (Kounios & Holcomb, 1994; West & Holcomb, 2000), b) that words with many semantic features are associated with larger N400 amplitudes than words with few semantic features (Rabovsky, Sommer, & Rahman, 2012; Amsel, 2011), and c) that words with many associates show a larger N400 than words with few associates (Laszlo & Federmeier, 2011; Müller, Duñabeitia, & Carreiras, 2010).

Taking into account the above evidence, it follows that the more or richer semantic information a word has, the more semantic activation it engages, and the larger the N400 it elicits (see, however, Taler, Kousaie, & López Zunini, 2013). In fact, it has been suggested that the N400 component may reflect the amount of semantic activity before the orthographic and semantic levels have settled, thus providing a temporal window into the activity generated by a stimulus in a distributed, cascaded, semantic system (Lazlo & Federmeier, 2011). Therefore, it is reasonable to think that if semantic-based accounts of the ambiguity advantage are correct, ambiguous words would cause a larger N400 than unambiguous words, as the former would engage a larger amount of semantic activation during word recognition than the latter. In contrast, if ambiguity effects are located at the orthographic level of representation (i.e., ambiguous words benefit from having stronger orthographic-to-orthographic connections), as suggested by Kawamoto et al. (1994), one would expect differences between ambiguous and unambiguous words on ERP components associated with orthographic processing. One of these components is the N200, a negative-going component peaking at about 200ms and which seems sensitive to orthographic processing (e.g., Bentin, Mouchetant-Rostaing, Giard, Echallier, & Pernier, 1999; Kramer & Donchin, 1987; Simon, Bernard, Lalonde, & Rebaï, 2006). For instance, N200 amplitudes are larger for orthographic stimuli (e.g., consonant strings and words) than for non-orthographic stimuli (e.g., symbols) (Bentin et al., 1999). Thus, following Kawamoto et al. (1994)'s model, ambiguous and unambiguous words should elicit a distinct pattern in the N200. The main aim of the present study was to test these two hypotheses regarding the source of the ambiguity advantage. To do so, we compared the amplitude of the N200 and the N400 elicited by ambiguous and unambiguous words while participants performed a LDT.

A second aim relates to the existence of distinct types of ambiguity. Indeed, semantic ambiguity is not a homogenous phenomenon, as not all ambiguous words are qualitatively similar. In particular, the degree of relatedness between the different meanings of an ambiguous word can vary widely. In the linguistics literature, ambiguous words have been categorized into at least two main classes: homonyms and polysemes. Homonyms have been defined as ambiguous words with unrelated meanings; for example, the homonym *yard* means both *a unit of measure* and *the ground that surrounds a house*, meanings that are clearly unrelated. On the other hand, polysemes have been defined as ambiguous words with related meanings (also known as *senses*); for instance, the polyseme *newspaper* refers to a wide range of related meanings or senses: (a) *a publication, usually issued daily or weekly*; (b) *a business organization that prints and distributes such a publication*; (c) *a single issue of such a publication*, and (d) *the paper on which a newspaper has been printed*. Given this distinction, one issue for word recognition research is whether such a linguistic categorization has psychological validity.

There is no consensus as to how relatedness of meanings (hereafter, ROM) affects ambiguous word recognition. On the one hand, some experimental data indicate that homonyms and polysemes are processed differently. A strong piece of evidence for this distinction can be found in Rodd et al. (2002)'s work, where the authors observed a facilitation for polysemes (i.e., polysemy or sense advantage) along with an inhibition for homonyms (i.e., homonymy or ambiguity disadvantage) in LDT. To account for these results, Rodd, Gaskell, and Marslen-Wilson (2004) developed a model of ambiguous word recognition, according to which polysemes would benefit during word recognition from having a single, richer semantic representation containing all their senses, whereas the separate semantic representations for homonyms would compete during word recognition. Importantly, Rodd et al.'s model obtained further support from subsequent LDT studies (Armstrong & Plaut, 2008, 2011; Klepousniotou & Baum, 2007; Tamminen, Cleland, Quinlan, & Gaskell, 2006). In addition, there is some neurophysiological evidence supporting it. For instance, Beretta, Fiorentino, and Poeppel (2005) found differences between polysemes and homonyms on the M350, a MEG component that reflects lexical processing and whose latencies are thought to be comparable to N400 amplitudes (Pylkkänen & Marantz, 2003). Specifically, in that study words with multiple related senses (i.e., polysemes) were seen to elicit earlier M350 peak latencies than words with few related senses. Furthermore, words with more than one meaning (i.e., homonyms) showed later M350 peak latencies than words with a single meaning. In contrast to the above findings, there are reports showing that polysemes and homonyms are processed similarly. In particular, several LDT studies have found that both polysemes and homonyms are recognized faster, and equally so, compared to unambiguous words (Hino, Kusunose, & Lupker, 2010; Hino, Pexman, & Lupker, 2006; Pexman et al., 2004). These authors, then, suggest that having multiple meanings, regardless of their ROM, leads to a stronger semantic-to-orthographic feedback during word recognition, facilitating orthographic processing and thus speeding up lexical decisions (Hino et al., 2010).

The second aim of the present study was to further explore the distinction between polysemes and homonyms by using ERP. If ROM does not affect the semantic activation of ambiguous words, as some of the above mentioned behavioral studies suggest (Hino et al., 2006; 2010; Pexman et al., 2004), no differences on the N400 between homonyms and polysemes should be expected, given that the N400 seems to be sensitive to semantic activation during word processing (e.g., Lazlo & Federmeier, 2011; Rabovsky et al., 2012). However, it might be that differences between homonyms and polysemes can be observed with electrophysiological measurements, as they are more sensitive than RTs (e.g., Chen, Shu, Liu, Zhao, & Li, 2007). In this case, we might expect that ROM modulates the amplitude of the N400.

To sum up, the purpose of the present study was to examine the behavioral and EEG correlates of ambiguous word processing by using a LDT. To do so, 1) we compared behavioral responses (RTs and %E) and EEG responses (the N200 and the N400) between ambiguous and unambiguous words, and 2) we compared behavioral responses (RTs and %E) and EEG responses (N400 amplitudes) between ambiguous words that differ in their ROM (i.e., homonyms vs polysemes). It should be noted that the present ERP study is not the first to examine ambiguous word processing. Indeed, some previous ERP studies have analyzed the neural correlates of ambiguous word processing by using a semantic priming paradigm (e.g. Klepousniotou, Pike, Steinhauer, & Gracco, 2012; Macgregor, Bouwsema, Klepousniotou, 2015). For instance, Klepousniotou et al. (2012) compared the N400 elicited by polysemes (e.g., *arm*) and homonyms (e.g., *ball*) when they were preceded by a related prime (e.g., *wrist-arm*, *green-mold*) relative to when an unrelated word served as prime (e.g., *reef-arm*, *energy-mold*). In addition, they manipulated the dominance of the prime, using words related either to the dominant meaning of the ambiguous word (e.g., *hit-ball*) or to its subordinate meaning (e.g., *dance-ball*). By doing so, they were able to examine the time course of the activation of the distinct meanings of ambiguous words during processing. In contrast, the present study was designed to explore whether ambiguity benefits lexical access and whether this benefit is modulated by the degree of relatedness between the distinct meanings of the ambiguous words. To our knowledge, the present work is the first ERP study to compare the processing of polysemes and homonyms in isolation.

2. Method

2.1. Participants

Twenty-five Spanish speakers (21 women; mean age 20.6 years, SD = 3.1) from the Universitat Rovira i Virgili (Tarragona, Spain) participated in the experiment. They were undergraduate students and were paid 10€ for their participation. All had either normal or corrected-to-normal vision, had no language difficulties or history of neurological disease, and 24 were right-handed. Prior to the experiment, participants signed an informed consent.

2.2. Design and materials

The experimental stimulus set consisted of 152 Spanish words: 76 ambiguous words and 76 unambiguous words[1] (see the Appendix). Stimuli were categorized as ambiguous or unambiguous according to Number-Of-Meanings (NOM) ratings (e.g., Kellas, et al., 1988; Pexman et al., 2004). The common procedure to obtain NOM ratings is as follows. Participants are asked to indicate how many meanings a particular string of letters has. They make their ratings by using a 3-point Likert scale: (0) *the word has no meaning*, (1) *the word has one meaning*, or (2) *the word has more than one meaning*. Words with values close to 2 are classified as ambiguous, and words with values close to 1 are classified as unambiguous. We employed different sources to obtain NOM ratings. NOM ratings for 125 words were taken from Haro, Ferré, Boada and Demestre (2017). NOM ratings for the remaining 27 words were provided by a group of 20 participants (15 women; mean age 22.3 years, $SD = 3.5$). According to this measure, unambiguous words had one meaning (NOM = 1.13, $SD = 0.19$) and ambiguous words had more than one meaning (NOM = 1.74, $SD = 0.19$), $t(144) = 19.68$, $p < .001$.

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[1] Due to data loss, 4 ambiguous words and 2 unambiguous words were not included in the analyses.

The set of 76 ambiguous words comprised 38 homonyms and 38 polysemes. The homonym/polyseme categorization was made on the basis of subjective ROM ratings, which were obtained from Haro et al. (2017). In that study, participants were asked to judge how related were the meanings of pairs of words, each pair containing the same ambiguous word and an associate related to one of its meanings (e.g., SIREN-*ambulance* [*warning alarm*] and SIREN-*sea* [*sea nymph*]). Participants were provided with a 9-point scale, ranging from 1 (unrelated meanings) to 9 (same meaning), to make their ratings. Using such a measure, homonyms are expected to have low ROM ratings, and polysemes high ROM ratings (for similar approaches, see Hino et al., 2010; Hino et al., 2006). Words with ROM ratings below 2.5 were categorized as homonyms, and those with ROM ratings above 2.5 were categorized as polysemes. Overall, the homonyms selected for this experiment averaged 1.86 (SD = 0.34) and the polysemes averaged 3.76 (SD = 0.93) on ROM ratings, t (70) = 11.76, p < .001. Importantly, homonyms and polysemes did not differ in NOM ratings, t (70) = 1.38, p = .17, which indicates that both types of ambiguous words had a similar number of meanings.

A large number of lexical and semantic variables that are known to affect word recognition were matched between ambiguous and unambiguous words, as well as between homonyms and polysemes (all ps > .05, see Table 1 for more details). These variables were drawn from several different sources. On the one hand, number of letters, number of syllables, logarithm of word frequency (log word frequency), mean Levenshtein distance of the 20 closest words (OLD20), number of neighbors, number of higher frequency neighbors, bigram frequency, trigram frequency, and logarithm of contextual diversity (log contextual diversity) were taken from EsPal (Duchon, Perea, Sebastián-Gallés, Martí, & Carreiras, 2013). On the other hand, familiarity, concreteness and subjective age of acquisition were taken from Haro et al. (2017). Given that subjective age of acquisition ratings for 27 words were not available from Haro et al.'s database, we asked a sample of 20 participants (15 women; mean age 22.3 years, *SD* = 3.5) to provide them.

Finally, we created a set of 152 pronounceable nonwords from the 152 experimental words, by using the Wuggy nonword generator (Keuleers & Brysbaert, 2010). Words and nonwords were matched in length, number of syllables, subsyllabic structure and transition frequencies.

Table 1

Characteristics of the stimulus set used in the experiment (standard deviations are shown in parentheses).

	NOM	ROM	FRE	CTD	FAM	AoA	LNG	SYL	CON	OLD	NEI	NHF	BFQ	TFQ
Unambiguous words	1.13 (0.19)	-	1.17 (0.66)	0.8 (0.51)	5.39 (1.11)	6.37 (2.38)	5.72 (1.8)	2.47 (0.81)	4.87 (1.21)	1.57 (0.45)	7.74 (8.03)	1.23 (2.36)	5442.95 (3207.86)	617.39 (708.59)
Ambiguous words	1.74 (0.19)	2.76 (1.17)	1.18 (0.44)	0.82 (0.34)	5.51 (0.75)	6.49 (1.8)	5.53 (1.03)	2.31 (0.55)	4.55 (0.73)	1.5 (0.39)	9.33 (9.52)	1.28 (2.06)	5553.1 (3190.51)	803.9 (695.74)
Polysemes	1.71 (0.18)	3.76 (0.93)	1.19 (0.45)	0.84 (0.34)	5.45 (0.81)	6.47 (1.92)	5.53 (0.93)	2.27 (0.51)	4.54 (0.71)	1.49 (0.35)	8.88 (8.79)	0.97 (1.88)	5098.96 (2299.69)	790.45 (516.31)
Homonyms	1.77 (0.19)	1.86 (0.34)	1.17 (0.44)	0.79 (0.34)	5.56 (0.69)	6.51 (1.71)	5.53 (1.13)	2.34 (0.58)	4.56 (0.75)	1.51 (0.44)	9.74 (10.22)	1.55 (2.2)	5959.44 (3802.3)	815.94 (831.13)

Note. NOM = subjective Number-Of-Meanings ratings; ROM = subjective Relatedness-Of-Meanings ratings; FRE = log word frequency; CTD = log contextual diversity; FAM = familiarity; AoA = subjective age-of-acquisition; LNG = word length; SYL = number of syllables; CON = concreteness; OLD = old20; NEI = number of substitution neighbors; NHF = number of higher frequency substitution neighbors; BFQ = mean bigram frequency; TFQ = mean trigram frequency.

2.3. Procedure

Participants performed a lexical decision task. Each trial began with an image of an eye displayed for 2000 ms, which indicated to participants that they were allowed to blink. The image was followed by a fixation point (i.e., "+") appearing in the center of the screen for 500 ms. Immediately after this, a string of letters (a word or a nonword) replaced the fixation point, and participants then had to decide whether the string was a Spanish word or not. They were instructed to press the "yes" labelled key of a keyboard with the right hand if the string of letters was a word, and to press the "no" labelled key of the keyboard with the left hand if it was not a word. The string of letters remained on the screen until participant's response or timeout (after 2000 ms). After responding, a feedback message (i.e., "ERROR" or "CORRECT") was displayed for 750 ms. The DMDX software (Forster & Forster, 2003) was used to display the stimuli and record the responses. The order of the experimental trials was randomized for each participant. Prior to the experiment, a practice block consisting of 12 trials (6 words and 6 nonwords) was presented. There were two brief breaks during the experiment.

2.4. EEG recording

Participants were seated in a comfortable chair in a sound attenuated and dimly illuminated room. The EEG was recorded from 32 Ag/AgCl electrodes attached to an elastic cap (ActiCap, Brain Products, Gilching, Germany) that was positioned according to the 10-20 system. One electrode was placed beneath the left eye to monitor blinking and vertical eye movements (VEOG), and another at the outer canthus of the right eye to monitor horizontal eye movements (HEOG). All scalp electrodes were referenced online to the right mastoid and re-referenced off-line to the average of the right and left mastoids. Electrode impedances were kept below 5 kΩ. All EEG and EOG channels were amplified using a actiCHamp amplifier (Brain Products Gilching, Germany).

Data was processed using BrainVision Analyzer 2 (Brain Products, Gilching, Germany). EEG was refiltered offline with a bandpass of 0.1-30 Hz 12 dB/oct, zerophase shift digital filter. Average ERPs were calculated per condition per participant from −100 to 800 ms relative to the onset of the word. A 100 ms pre-target period was used as baseline. Trials were rejected if the amplitude on any channel exceeded ± 75 μV, and also if deflections on any channel exceeded ± 150 μV. Less than 5% of trials were rejected after applying such trimming procedures. Only correct response trials were included in the averages.

3. Results

3.1. Behavioral results

The data from one participant with more than 15% of errors were discarded from both the behavioral and ERP analyses. RTs that exceeded 2 *SD* of each participant's mean were also rejected (3.7% of the data). In addition, we excluded two unambiguous words from the analyses due to a high percentage of errors (>70%). We then calculated the mean of RTs for correct responses and the mean %E across experimental conditions (see Table 2). Mean RTs and mean %E were analyzed with separated t-tests (paired t-tests for participants' analyses, and unpaired t-tests for items' analyses).

Table 2

Mean RT (in ms), and %E (percentage of error rates) (standard error in parentheses)

Ambiguity	ROM	RT	%E
Unambiguous words		590.51 (12.69)	8.33 (1.09)
Ambiguous words		572.70 (12.53)	3.25 (0.47)
	Polysemes	575.66 (11.92)	3.63 (0.57)
	Homonyms	570.20 (13.53)	2.92 (0.67)

Ambiguous words were recognized faster than unambiguous words, $t_1(23) = 7.03$, $p < .001$, $t_2(142) = 3.05$, $p = .003$. Likewise, ambiguous words were recognized more accurately than unambiguous words, $t_1(23) = 4.79$, $p < .001$, $t_2(142) = 3.19$, $p = .002$. On the other hand, no differences were found between homonyms and polysemes, either in RTs, $t_1(23) = 1.04$, $p = .31$, $t_2(70) = 1.01$, $p = .32$, or in %E, $t_1(23) = .86$, $p = .40$, $t_2(70) = .67$, $p = .50$.

3.2. ERP results

ERP analyses were focused on the N200 and N400 components. N200 was measured by computing mean amplitudes between 150-250 ms after word onset, whereas the time range for the N400 component was established between 350-450 ms after word onset. Several repeated-measures analyses of variance (ANOVAs) were performed to examine differences between ambiguous and unambiguous words on the N200 and the N400 (i.e., ambiguity effects), and to examine differences between homonyms and polysemes on the N400 (i.e., ROM effects).

3.2.1. Ambiguity effects

An ANOVA was conducted with the factors of ambiguity (ambiguous and unambiguous words) and electrode site (28 electrodes). We also carried out other ANOVAs to examine separately midline electrodes: ambiguity (ambiguous and unambiguous words) x electrode site (Fz, Cz, Pz, Oz), and lateral electrodes: ambiguity (ambiguous and unambiguous words) x hemisphere (left/right) x electrode site (Fp1/Fp2, F3/F4, F7/F8, FC1/FC2, FC5/FC6, C3/C4, T7/T8, CP1/CP2, CP5/CP6, P3/P4, P7/P8, O1/O2). All factors were within-subjects. For effects involving more than one degree of freedom, Greenhouse-Geisser correction was applied (corrected p-values are reported). Grand average waveforms for ambiguous and unambiguous words are shown in Figure 1

3.2.1.1 N200

The analysis of the data from all the electrodes failed to show any difference between ambiguous and unambiguous words on N200 amplitudes, F (1, 23) = 0.08, MSE = 1.36, p = .78. No other significant effects or interactions were found (all ps > .1).

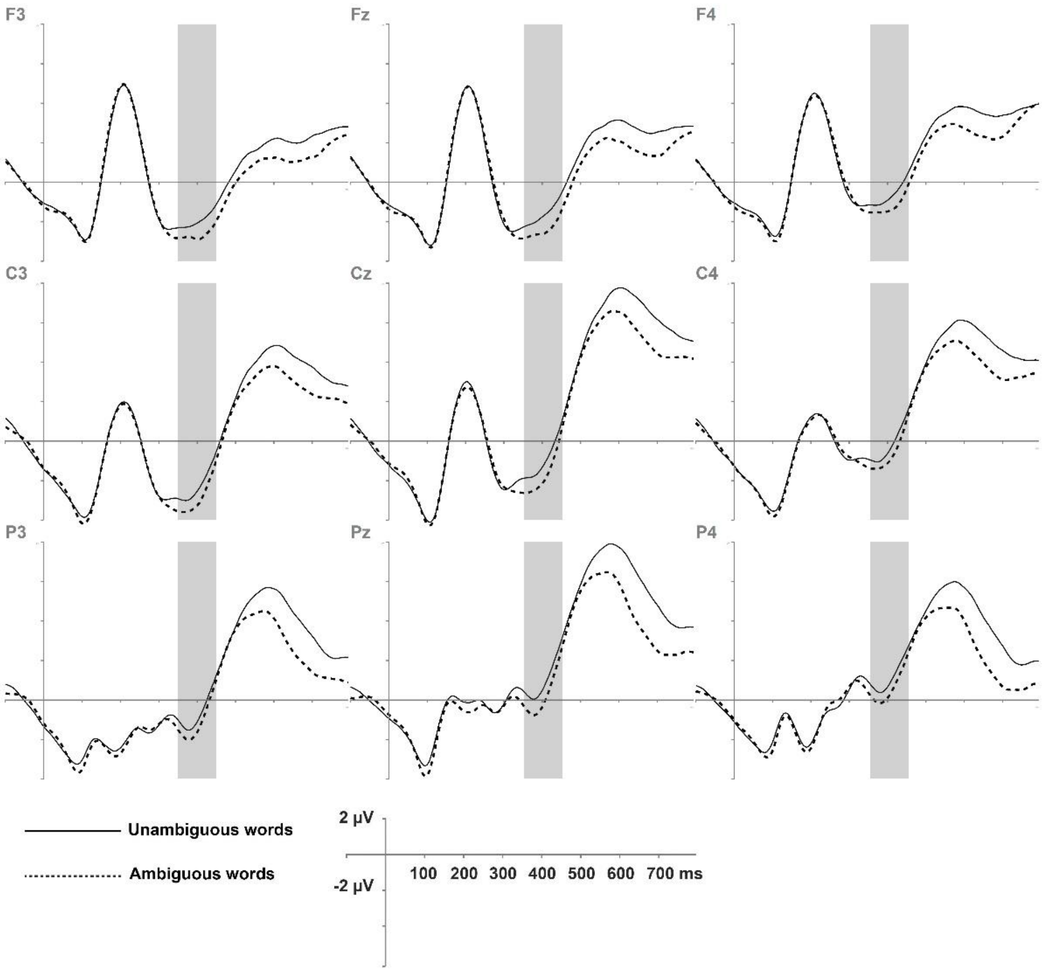

Figure 1. *Grand average waveforms for ambiguous and unambiguous words for nine representative electrodes (negativity is plotted down). The shaded area represents the time range for the N400 component (350-450 ms).*

3.2.1.2 N400

The analysis including data from all the electrodes revealed a main effect of ambiguity, F (1, 23) = 5.07, MSE = 84.22, p = .034. Ambiguous words elicited larger N400s (-1.70 μV) than unambiguous words (-1.20 μV). No interaction was found between ambiguity and electrode site, F (27, 621) = 1.53, MSE = 5.26, p = .20. The main effect of ambiguity on the N400 was also found in the analysis of midline electrodes, F (1, 23) = 4.95, MSE = 21.21, p = .036, as well as in the analysis of lateral electrodes, F (1, 23) = 4.95, MSE = 64.51, p = .036. Of note, no significant interaction was found between ambiguity and hemisphere, F (1, 23) = 0.16, MSE = 0.29, p = .69.

3.2.2. ROM effects

The same analyses as those conducted to examine ambiguity effects were conducted to compare the N400 elicited by homonyms and polysemes (i.e., ROM factor). Grand average waveforms for homonyms, polysemes and unambiguous words are shown in Figure 2. The main effect of ROM did not reach significance in the analysis including data from all the electrodes, F (1, 23) = 0.16, MSE = 5.62, p = .70. Homonyms and polysemes showed similar N400s(-1.75 μV vs -1.62 μV). No interaction was observed between ROM and electrode site, F (27, 621) = 1.41, MSE = 11.55, p = .24. Concerning midline and lateral separate analyses, no main effect of ROM was found in the analysis of midline electrodes, F (1, 23) = 0.21, MSE = 2.06, p = .65, nor in the analysis of lateral electrodes, F (1, 23) = 0.14, MSE = 3.90, p = .71. Finally, the interaction between ROM and hemisphere was not significant, F (1, 23) = 0.01, MSE = 0.30, p = .93. No other relevant effects or interactions were found.

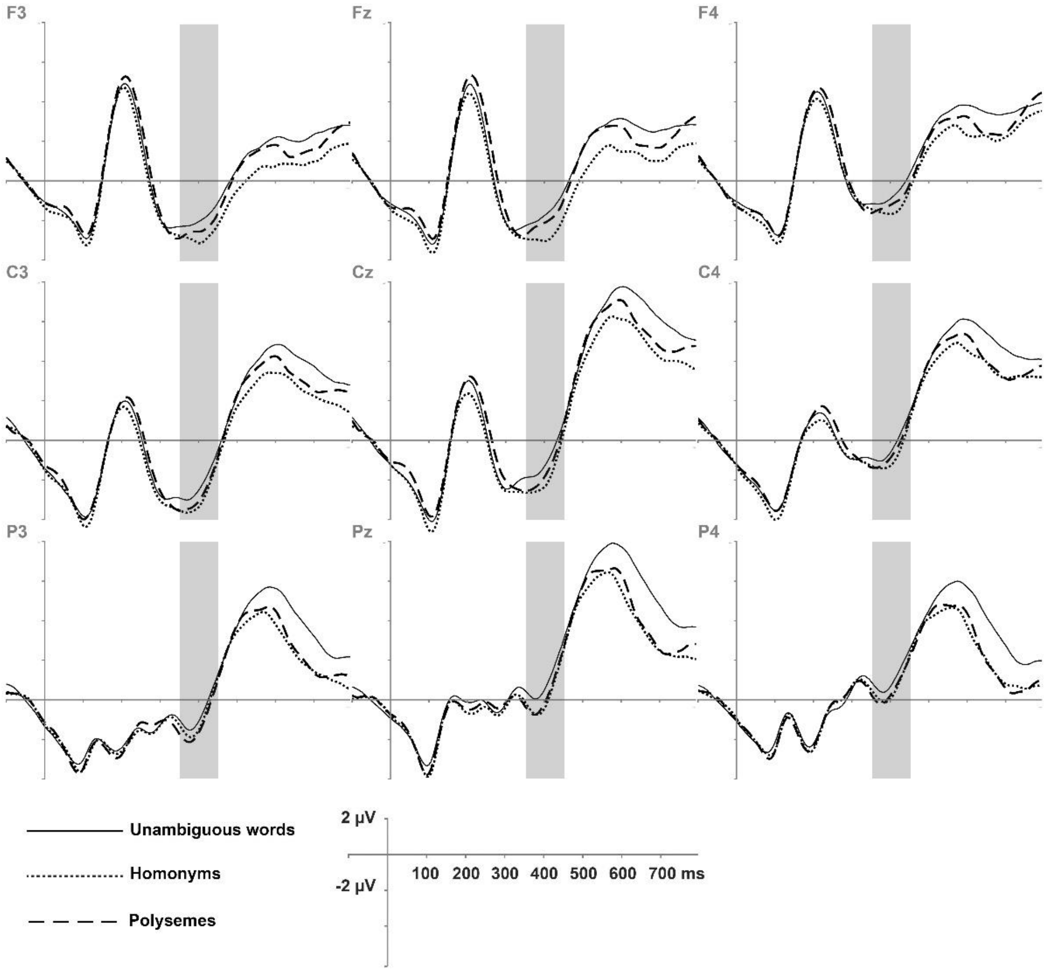

Figure 2. *Grand average waveforms for homonyms, polysemes and unambiguous words for nine representative electrodes (negativity is plotted down). The shaded area represents the time range for the N400 component (350-450 ms).*

4. Discussion

The aim of the present study was to obtain behavioral and EEG correlates of ambiguous word processing. As far as we know, this is the first ERP study to examine the processing of polysemes and homonyms in isolation. On the one hand, we compared ambiguous words to unambiguous words in a LDT. The results showed faster and more accurate behavioral responses and larger N400 amplitudes for ambiguous words in comparison to unambiguous words. In contrast, there were no differences in the N200 between both types of words. On the other hand, we examined ambiguous words differing in ROM. In particular, we compared ambiguous words with unrelated meanings (i.e., homonyms) to ambiguous words with related meanings (i.e., polysemes). The results showed that homonyms and polysemes exhibited a similar degree of facilitation in behavioral responses relative to unambiguous words. Furthermore, the two types of ambiguous words did not differ in the N400. In what follows, we will discuss separately the ambiguity effects and the ROM effects.

4.1. Ambiguity effects

In line with previous reports of a facilitation for ambiguous words in LDT, behavioral data showed that ambiguous words were recognized faster and more accurately than unambiguous words (Borowsky & Masson, 1996; Hino et al., 2002; Hino & Lupker, 1996; Jastrzembski & Stanners, 1975; Jastrzembski, 1981; Kellas et al., 1988; Millis & Button, 1989; Pexman et al., 2004). More importantly, EEG data revealed that semantic ambiguity modulated the N400, but not the N200. These electrophysiological findings contribute to a better understanding of the advantage for ambiguous words over unambiguous words in LDT. Thus, the absence of differences between ambiguous and unambiguous words on the N200 does not provide support for the models that locate the source of the ambiguity advantage at the orthographic level (e.g., Kawamoto et al., 1994). In contrast, considering that the N400 seems to reflect activity taking place at the semantic level of representation (e.g., Lazlo & Federmeier, 2011), the larger N400 observed for ambiguous words would indicate that they engage more semantic activation than unambiguous words during word recognition. This evidence is compatible with the above described semantic accounts of the ambiguity advantage. Such accounts suggest that as ambiguous words are represented by more than one semantic representation, they would benefit during word recognition either from an increase in the global activation at the semantic level of representation (Borowsky & Masson, 1996) or from a larger semantic-to-orthographic feedback (Hino & Lupker, 1996).

It is also worth noting here that the facilitation effect found for ambiguous words resembles the effects of semantic richness in word recognition; that is, the more or richer semantic information a word has, the faster is its recognition (Pexman et al., 2008). This facilitative effect has been demonstrated with different manipulations and variables, such as the number of semantic features (e.g., Amsel, 2011), number of associates (e.g., Müller et al., 2010), and concreteness (e.g., Kounios & Holcomb, 1994), among others. In addition, the N400 seems to be modulated by some of these variables, with increased N400 amplitudes for semantically richer words (Rabovsky et al., 2012), in agreement with the present electrophysiological data. In light of these findings, it seems that the advantage for ambiguous words fits well within semantic richness effects in word recognition and may be explained by the same mechanisms. To explore this issue in greater depth, we measured the correlation between NOM and some relevant semantic richness variables (i.e., number of word associates and contextual diversity measures). NOM ratings and number of word associates were obtained from Haro et al. (2017), whereas log contextual diversity was obtained from Duchon et al. (2013). We found a significant correlation between NOM ratings and semantic richness variables: number of word associates, $r = .12$, $p = .004$, and log contextual diversity, $r = .40$, $p < .001$. In addition to that, we also conducted a hierarchical regression analysis to examine if NOM influences lexical decision times beyond the effect of those semantic richness variables to which it is correlated. Of note, given that the experimental stimuli of our study were matched on a large number of variables, we conducted this analysis with a more heterogeneous (and larger) set of words. Hence, the regression analysis was conducted with the 260 words of the database of Haro et al. (2017), for which lexical decision data were available from González-Nosti et al. (2014), a large LDT study of Spanish words. The dependent variable was the RT for lexical decisions. The independent variables were entered as predictors of RTs on three steps. Word length, number of syllables, log word frequency, number of neighbors, OLD20, bigram frequency, and trigram frequency were entered as predictors in the first step. Number of associates, concreteness, and log contextual diversity were entered in the second step. Finally, NOM ratings were entered in the third step. Number of syllables, log word frequency and number of neighbors, OLD20, bigram frequency, and trigram frequency were obtained from Duchon et al. (2013), whereas the ratings for the rest of variables were taken from Haro et al. (2017). The results revealed a significant facilitative effect of NOM ratings on RTs, $\beta = -.14$, $t = 2.37$, $p = .019$ (detailed results of the regression analysis are presented in Appendix B). In sum, these findings show that number of meanings is correlated with some semantic richness variables and that the facilitative effect of NOM on lexical decision times cannot be explained by the effect of such variables. We consider that these findings provide further support for considering NOM as a semantic richness variable and for its unique role in contributing to LDT performance.

4.2. ROM effects

The results of the present study failed to show any effect of ROM either on behavioral or electrophysiological measures. This null effect is in line with several studies showing that homonyms and polysemes are similarly processed in LDT, with faster responses for both types of ambiguous words in comparison to unambiguous words and with no differences between them (Hino, et al., 2010; Hino, et al., 2006; Pexman et al., 2004). In contrast, this finding is incompatible with other studies that reported a distinct response pattern for homonyms and polysemes, both in behavioral performance (Armstrong & Plaut, 2008, 2011; Klepousniotou & Baum, 2007; Rodd et al., 2002; Tamminen et al., 2006) and in neurophysiological data (Beretta et al., 2005). A possible explanation for these divergent results may be the different approach employed to the categorization of ambiguous words across studies. In the present study, as well as in those where no differences were found between both types of ambiguous words, homonyms and polysemes were categorized according to subjective ROM measures. This represents a crucial methodological difference with respect to those LDT studies showing that ROM affects word processing, given that they mainly relied on dictionary definitions to classify the words (see, however, Rodd et al., 2002, Experiment 1). Such an approach is based on the assumption that unrelated meanings are listed in separate dictionary entries, whereas related meanings are listed under the same dictionary entry. Within this approach, then, homonyms are taken to be words with more than one dictionary entry, whereas polysemes are words having many dictionary senses within a single entry. Although more research is needed to compare directly the experimental effects of using these two distinct criteria, an interesting finding is that subjective measures of semantic ambiguity seem to be better predictors of lexical decision times than dictionary measures (Fraga, Padrón, Perea, & Comesaña, 2017).

Another possible explanation for the null ROM effect is that LDT is a task that does not engage very much semantic processing. Indeed, there is some evidence showing that ambiguous word processing may be modulated by the requirements of the experimental task. For instance, in contrast to the ambiguity advantage commonly found in LDT, ambiguous words are usually responded to more slowly than unambiguous words in more semantically engaging tasks, such as semantic categorization, sense judgement and semantic relatedness tasks (see Eddington & Tokowicz, 2016, for a review). These tasks, unlike LDT, usually require a specific meaning of the ambiguous word to be activated. Consequently, this may increase the competition between the multiple meanings of the ambiguous words, leading to slower responses for ambiguous words in comparison to unambiguous words. Furthermore, a significant ROM effect has also been observed in these tasks. For example, Hino et al. (2006) found than homonyms were responded to more slowly and less accurately than unambiguous words in two semantic categorization tasks (using the semantic category “living thing” [Experiment 2] and “human related” [Experiment 5]). In contrast, polysemes showed faster and more accurate responses than homonyms. In a similar vein, Brown (2008) reported that pairs of homonym verb phrases (e.g., *banked the plane – blanked the money*) were responded to more slowly than pairs of polyseme verb phrases (e.g., *broke the glass – broke the radio*) in a sense judgment task. So, this evidence, although limited, suggests that ROM effects may emerge in tasks requiring exhaustive semantic activation.

Taking all the above into consideration, the results of the present study suggest that the number of meanings (i.e., ambiguity), but not ROM (i.e., the distinction between polysemes and homonyms), influences word recognition when it is assessed with a LDT. These findings have implications for models of semantic ambiguity processing and representation. In particular, the null ROM effect is a challenge for Rodd et al. (2004)’s model, since it postulates that polysemes are represented and processed in a different way from homonyms. Namely, it assumes that all the related meanings of a polyseme are stored in a single, richer semantic representation (i.e., single shared representation for polysemes), whereas the unrelated meanings of a homonym would be stored in separated semantic representations. Hence the model predicts an advantage for polysemes in LDT, as these words would benefit from having a single, richer semantic representation, and a disadvantage for homonyms, since their multiple, unrelated semantic representations are thought to compete during word processing. Importantly, in contrast to Rodd et al. (2004), some authors have suggested that both types of ambiguous words may be represented similarly, that is, with each homonym or polyseme meaning having a separate entry in the mental lexicon (i.e., separated representation for polysemes; e.g., Klein & Murphy, 2001, 2002). Thus, according to interactive activation principles, if each separate meaning of a homonym or polyseme provides an independent stream of feedback to its linked orthographic representation, both types of ambiguous words would trigger a similar amount of semantic feedback and, thus, no differences should be expected between them in LDT (Hino et al., 2010). Hence, the null ROM effect found in the present study seems compatible with proposals claiming that homonyms and polysemes are represented similarly, that is, through separate representations.

To sum up, in the present study we have shown that ambiguous words elicit faster and more accurate behavioral responses and larger N400s than unambiguous words in a LDT. This suggests that the cause of the ambiguity advantage is that ambiguous words engage a larger amount of semantic activation during word recognition than unambiguous words. In addition, we have observed no differences between homonyms and polysemes, either in behavioral or electrophysiological data. This seems to indicate that ROM does not affect ambiguous word recognition in lexical decision tasks, and that both types of ambiguous words benefit from triggering a similar amount of semantic activation.

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APPENDIX A

Experimental stimuli

Word	English trans.	Condition	NOM	ROM
ácido	sour / acid	homonym	1.54	2.31
acuario	aquarius /aquarium	homonym	1.58	1.64
baja	fall in price / time off sick	homonym	1.90	1.68
burbuja	bubble	homonym	1.56	1.96
campaña	campaign / countryside	homonym	1.91	1.56
caña	rod/beer	homonym	1.88	1.67
código	code	homonym	1.25	2.28
colonia	colony / cologne	homonym	1.74	2.25
cómoda	chest of drawers / comfortable	homonym	1.76	2.04
copa	cup / crown	homonym	1.96	1.96
ficha	piece / card	homonym	1.70	1.96
físico	physical/physicist	homonym	1.88	2.44
fuente	fountain / source	homonym	1.92	1.33
guion	hyphen / script	homonym	1.79	2.00
heroína	heroine / heroin	homonym	1.61	1.87
jota	J (letter) / jota (Spanish dance)	homonym	1.83	1.32
lima	lime / rasp	homonym	1.81	1.26
manto	cape / blanket	homonym	1.08	1.85
matriz	womb / matrix	homonym	1.65	1.71
mona	female monkey / pretty	homonym	2.00	1.74
monitor	monitor / instructor	homonym	1.62	2.10
notas	mark / memo	homonym	1.90	2.41
palma	palm	homonym	1.92	1.57
partida	departure / round (game)	homonym	1.74	2.17
pasta	pasta / money	homonym	2.00	1.89
patrón	boss / pattern	homonym	1.91	1.95
pensión	pension / hostel	homonym	1.74	2.24
perfil	profile	homonym	2.00	2.37
pipa	pipe / seed	homonym	1.87	1.48

plancha	sheet/iron	homonym	1.90	1.88
planear	plan/glide	homonym	1.90	1.85
recto	straight / rectum	homonym	1.65	1.52
rollo	roll / bore	homonym	1.86	1.72
sirena	siren	homonym	1.78	1.16
tabla	board / table	homonym	1.79	1.84
tanque	tank	homonym	1.71	2.39
tono	tone	homonym	1.63	1.57
vale	OK / voucher	homonym	1.90	1.61
acento	accent / emphasis	polyseme	1.67	3.38
activo	active	polyseme	1.81	5.15
aguja	needle	polyseme	1.39	2.57
armar	arm/assemble	polyseme	1.65	3.05
barra	bar	polyseme	1.81	2.63
bestia	beast/brute	polyseme	1.76	5.47
billete	bill/ticket	polyseme	1.75	3.52
bombón	chocolate/beauty	polyseme	1.43	3.38
brote	sprout / outbreak	polyseme	1.86	4.11
busto	bust	polyseme	1.30	3.91
capa	layer / cape	polyseme	1.87	2.74
cartas	cards / letters	polyseme	1.76	3.30
cólera	anger/cholera	polyseme	1.58	3.44
damas	draughts (game) / ladies	polyseme	1.81	3.00
fracción	part / section / split / fraction	polyseme	1.61	5.48
genio	genie / genius	polyseme	1.52	2.76
globo	balloon/globe	polyseme	1.75	3.65
grano	grain/spot	polyseme	1.92	2.89
letra	letter	polyseme	1.62	4.26
listo	ready / clever	polyseme	1.65	4.32
manual	manual	polyseme	1.74	3.21
marca	mark / brand	polyseme	1.95	2.50
pasajero	passenger / temporary	polyseme	1.50	4.30
pluma	feather / quill	polyseme	2.00	4.17

rango	rank / status	polyseme	1.43	5.39
rosa	rose / pink	polyseme	1.91	3.56
señal	gesture / signal / mark	polyseme	1.85	4.24
solar	solar / site	polyseme	1.83	2.61
sólido	solid /strong	polyseme	1.46	3.59
talla	size / height	polyseme	1.67	6.08
titular	title / principal	polyseme	1.88	3.82
tronco	trunk (tree) / trunk (body)	polyseme	1.65	3.91
virgen	virgin	polyseme	1.91	3.08
vocal	vocal/vowel	polyseme	1.75	4.39
abeja	bee	unambiguous	1.05	
acabar	to finish	unambiguous	1.30	
aceite	oil	unambiguous	1.17	
acero	steel	unambiguous	1.00	
agua	water	unambiguous	1.04	
alcalde	mayor	unambiguous	1.05	
alma	soul (of a person)	unambiguous	1.15	
almirante	admiral	unambiguous	1.15	
amar	to love	unambiguous	1.10	
bandera	flag (symbol of a country)	unambiguous	1.48	
barranco	ravine	unambiguous	1.09	
baúl	trunk (storage)	unambiguous	1.04	
bayeta	baize	unambiguous	0.83	
biólogo	biologist	unambiguous	1.07	
bruma	mist	unambiguous	0.50	
caballero	gentleman	unambiguous	1.81	
calor	hot (temperature)	unambiguous	1.08	
camioneta	van	unambiguous	1.04	
caos	chaos	unambiguous	1.45	
casta	lineage	unambiguous	1.05	
cerilla	match (stick for lighting fire)	unambiguous	1.04	
cerveza	beer	unambiguous	1.00	
clan	clan	unambiguous	1.40	

coágulo	clot (blood)	unambiguous	1.08
cofre	chest (box)	unambiguous	1.09
coleta	pigtail (hairstyle)	unambiguous	1.35
contusión	contusion	unambiguous	1.09
cuestionario	questionnaire	unambiguous	1.04
década	decade	unambiguous	1.09
domingo	Sunday	unambiguous	1.13
ecuación	equation (mathematical expression)	unambiguous	1.13
error	error	unambiguous	1.09
fe	faith (religious belief)	unambiguous	1.00
flores	flowers	unambiguous	1.19
gama	spectrum	unambiguous	1.50
geología	geology	unambiguous	1.00
guitarra	guitar	unambiguous	1.04
hallar	to find	unambiguous	1.10
hélice	propeller	unambiguous	1.13
hijo	son	unambiguous	1.04
himno	anthem	unambiguous	1.00
hito	milestone	unambiguous	0.80
humo	smoke	unambiguous	1.22
ira	anger	unambiguous	1.00
jabón	soap (bar of soap)	unambiguous	1.00
jeringa	syringe	unambiguous	1.00
junio	June	unambiguous	1.04
labor	labour (work)	unambiguous	1.30
legado	legacy	unambiguous	1.15
lencería	lingerie	unambiguous	1.17
llegar	to arrive	unambiguous	1.15
lograr	to achieve	unambiguous	1.10
mar	sea	unambiguous	1.76
martillo	hammer	unambiguous	1.43
mente	mind (brain)	unambiguous	1.05
miel	honey (sweet fluid made by bees)	unambiguous	1.07

modo	mode (manner)	unambiguous	1.35
neutrón	neutron	unambiguous	1.00
optar	to opt	unambiguous	1.10
pan	bread	unambiguous	1.04
paraguas	umbrella	unambiguous	1.09
pensar	to think	unambiguous	1.05
rato	little while	unambiguous	1.05
recado	errand	unambiguous	1.20
riñón	kidney	unambiguous	1.04
sede	headquarters	unambiguous	1.30
sobrina	niece	unambiguous	1.00
tarea	homework	unambiguous	1.25
teclado	keyboard	unambiguous	1.26
usar	to use	unambiguous	1.15
vejez	old age	unambiguous	1.04
zona	zone	unambiguous	1.10

APPENDIX B

Response times regression coefficients for 260 words from the database of Haro et al. (2017), for which lexical decision data were available from González-Nosti et al. (2014). P-values are represented with asterisks. The reported regression coefficients correspond to the variables entered in that particular step.

Predictor		
Step 1: Lexical variables		
Word length	-.05	
Number of syllables	.18	*
Log word frequency	-.49	***
OLD20	.16	
Number of neighbors	.00	
Bigram frequency	-.04	
Trigram frequency	.07	
Adjusted R^2	.40	***
Change in R^2	.40	***
Step 2: Semantic variables		
Number of associates	-.02	
Log contextual diversity	-.57	*
Concreteness	-.14	*
Adjusted R^2	.41	***
Change in R^2	.01	*
Step 3: Ambiguity measures		
NOM	-.14	*

Adjusted R^2	.42	***
Change in R^2	.01	*

Note. * $p < .05$; *** $p < .001$