Semantic integration of novel word meanings after a single exposure in context

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Abstract

We investigated the influence of sentence context on initial integration of novel word meanings into semantic memory. Adults read strongly or weakly constrained sentences ending in known and unknown (novel) words as electrical brain activity was recorded. Word knowledge was assessed via a lexical decision task where recently seen known and unknown word sentence endings served as primes for related, unrelated, and synonym/identical target words. N400 amplitudes to target words preceded by known word primes were reduced by prime relatedness. Critically, N400 amplitudes to targets preceded by novel words also varied with prime relatedness, but only if they initially appeared in highly constraining sentences. These results demonstrate that electrical brain activity accompanying one-shot contextual word learning is modulated by contextual constraint and reveals a rapid neural process that can integrate information about word meanings into the mental lexicon.

Keywords: word learning; N400; event-related brain potentials; language learning

Word learning is a lifelong process. However, research on adult first language word learning has largely been eclipsed by word learning in children and in adult bilinguals. Though these areas of study have yielded important insights into word learning, the mode by which adults learn words in their native language is likely to differ from that of children. For example, while children typically map words to novel or unnamed concepts (Markman & Wachtel, 1988), adults more often learn nuanced meanings for name-known concepts (e.g. jocund/happy). Furthermore, younger children often learn words in oral and ostensive contexts, whereas older children and adults acquire words largely via incidental learning in various language contexts, especially during reading (Jenkins, Stein, & Wysocki, 1984; Sternberg, 1987).

Word learning can be remarkably fast under the right conditions. A single exposure to a novel word can be sufficient for a learner to infer its probable meaning (Carey & Bartlett, 1978; Dollaghan, 1985). However, little is known about contextual influences on the representation of novel word meanings learned from a single exposure, how quickly this new information is integrated with the existing semantic system, or what the neural correlates of this rapid learning may be. The main goal of our research is to explore these issues by measuring modulation of event-related brain potentials (ERPs) during single trial word learning in sentence contexts of varying strength.

Background

Studies of adult first and second language learners provide evidence for rapid neural changes in young adults in association with word learning in both first (L1) and second (L2) languages (Borovsky, Elman, & Kutas, 2007; McLaughlin, Osterhout, & Kim, 2004; Mestres-Misse, Rodriguez-Fornells, & Münte, 2006; Perfetti, Wlotko, & Hart, 2005; Stein et al., 2006). For example, McLaughlin and colleagues (2004) compared brain responses in native French speakers to undergraduates learning French as a second language. They found that college language learner's brain responses during a semantic priming task using French words were indistinguishable from native speakers after only a few months of instruction. Their findings demonstrate not only that the brain may process word meanings acquired in childhood and adulthood similarly, but that lexical acquisition over extended training can be measured by modulations in neural activation.

L1 word learning studies have suggested that even faster neural changes due to word learning are possible (Perfetti, Wlotko & Hart, 2005; Mestres-Missé, Rodriguez-Fornells & Münte, 2007; Borovsky, Elman & Kutas, 2007). For example, Mestres-Missé and colleagues (2007) found that three presentations of a novel word in progressively constraining sentence contexts can significantly modulate the associated neural responses. We (Borovsky, Elman & Kutas, 2007) further examined the influence of contextual constraint on novel word usage after only a single presentation. Novel words were presented in a single highly or weakly constraining sentence context. Subsequently, participants were asked to differentiate between appropriate and inappropriate usages of these novel words as objects of particular verbs. Participants were able to incorporate significant information about the proper usage of novel words after a single exposure, but only when the novel words initially appeared in highly (and not in weakly) constraint contexts.

While comprehending a word's usage is an important aspect of vocabulary acquisition, knowledge of a word's relationship to other words is also vital. For example, part of our understanding of the words CAT, DOG and CHAIR, is that CAT and DOG have many overlapping similarities and features that neither shares with CHAIR. Research has indicated that adults can gain significant knowledge of these

relationships with a few exposures in sentences (Mestres-Misse et. al, 2006). In the present study, we ask whether even one exposure suffices to enable learners to incorporate the novel word into the semantic network that functionally connects words with related meanings, and how sentence contexts might influence this acquisition, if at all. More specifically, we use an event-related brain potential (ERP) component - the N400 - to index knowledge of word meaning via semantic priming when unknown words are initially presented in sentences that either strongly or weakly constrain their meaning.

The N400 is an ERP component that is a sensitive measure of semantic processing. It is a negative going wave with a centroparietal maximum that peaks approximately 400ms after the onset of any potentially meaningful stimulus. The N400 amplitude of word is reduced when it is (contextually) expected or when features associated with its meaning are easily integrated within the surrounding context (Kutas & Federmeier, 2000; Kutas & Hillyard, 1980) Additionally, the N400 to orthographically legal and pronounceable nonwords (pseudowords) is large (Ziegler, Besson, Jacobs, Nazir, & Carr, 1997); it is not present for true nonwords that do not have orthographically legal spellings, or are unpronounceable (Bentin, 1987). The N400 is modulated by lexical frequency and is larger for lower frequency words in lists (Smith & Halgren, 1987). N400 amplitude, thus, is associated with a word's meaningfulness in a given context, ranging from small in amplitude when a word is very easily integrated or understood, to large when a word's meaning is unknown. These findings suggest that N400 amplitude is likely to vary with the degree to which the meaning of a newly encountered word is appreciated – a prediction that has been borne out by recent research in L2 and L1 word learning (e.g., McLaughlin, Osterhout & Kim, 2004; Mestres-Misse et. al. 2007).

Target words preceded, or primed, by an identical or related word (for example doctor- NURSE, or doctor-DOCTOR) are associated not only with faster response times (e.g., Neely, 1991), but with reduced N400 amplitudes (Bentin, McCarthy, & Wood, 1985; Nobre & McCarthy, 1994), compared to target words preceded by words that are unrelated in meaning, or by nonwords (i.e. doctor-CHAIR, or doctor-FOOP). Such semantic priming effects have been interpreted as reflecting the functional organization of words in the brain (Collins & Loftus, 1975; Lucas, 2000).

In this study, we examine the impact of context on novel words' initial integration in semantic memory via semantic priming. Following an initial exposure in a strongly or weakly constraining sentence, we gauge successful word meaning acquisition by means of semantic priming in a lexical decision task. In this case, N400 amplitude modulation to a target word by a recently experienced prime word is taken as an index of semantic integration of the novel word's meaning into semantic memory. We use N400 amplitudes to gauge how contextual constraint influences acquisition of word meaning by contrasting how these novel words prime target words that are identical, related, or unrelated in (implied) meaning. We can also explore how context impacts the integration of novel word meaning into the mental lexicon by assessing the interaction between the priming effect and contextual constraint.

Methods

Participants:

24 college students (13 F) were given credit or paid $7/hr for their participation. Ages ranged between 18-30 (mean: 19.50). All participants were right-handed, native English speakers and had no significant exposure to another language at least before the age of 12. Participants reported no history of mental illness, learning disability, language impairment, drug abuse, or neurological trauma. All participants had normal hearing and normal (or corrected to normal) vision. An additional 11 participated but were not analyzed: 5 had excessive blinking or motion artifact, 1 due to equipment failure, and 5 reported a characteristic which disqualified them from analysis (4 had significant childhood second language exposure, 1 had non-normal vision.)

Materials:

Stimuli consisted of 132 sentence pairs selected from Federmeier and Kutas (1999), and 528 word pairs selected to correspond with 132 sentence final words. Both are described in detail below:

Sentences: 64 high constraint and 64 low constraint sentence pairs were selected from Federmeier and Kutas (1999). These pairs had previously been extensively normed to ensure adequate levels of cloze probability for high and low constraint sentences. Sentence pairs consisted of an initial sentence that set up an expectation of a meaning and item category, and a second sentence that was matched with sentence final words that were either plausible and expected known word sentence completions (Federmeier & Kutas, 1999), or unknown pseudowords, yielding 32 sentences in each of four main conditions: 1) High constraint / Known word ending, 2) High Constraint / Unknown word ending 3) Low constraint / Known word ending and 4) Low constraint / Unknown word ending (see Table 1a for examples). Sentences pairs were counterbalanced such that each appeared with a Known and Unknown ending equally across all versions, but not repeated within a subject. Known word target items consisted of words in 64 categories, and these categories were used as the basis for selecting semantically related and unrelated prime-target pairs, described below.

Word-Pairs: 528 word pairs were constructed that consisted of a prime followed by a target word presented one stimulus at a time. Since repetition is known to diminish N400 effects (Van Petten, Kutas, Kluender, Mitchiner, & McIsaac, 1991), and it is unclear if repetition and constraint might interact, we designed the priming task such that the N400 of interest was to the presentation of a target word that followed a prime that was either a Known or Unknown words from the sentence endings described above. The N400 effect of interest would thus be elicited to previously unseen real

word targets in three conditions: 1) Synonym/Identical (Syn/ID: rabbit-RABBIT), 2) Related (Rel: rabbit-MOUSE), and 3) Unrelated (Unrel: rabbit-RIBBON). Unrel and Rel word pairs were selected to be closely matched to other target conditions in word frequency ($F(2, 353)=1.09$, $p=0.34$) length ($F<1$)), syllables ($F<1$), and phonemes ($F<1$), as reported by the MRC psycholinguistic database (Wilson, 1988). Efforts were also made to match targets as closely as possible on Concreteness, Familiarity and Imageability ratings when they were available. Additionally, targets in each condition did not differ as a function of constraint in frequency [Syn/ID: $|t| <1$, Rel: $|t| <1$, Unrel: $t(130)=1.06$, $p=0.29$] length [Syn/ID: $t(130)=-1.45$, $p=0.15$, Rel: $|t| <1$, Unrel: $t(130)=-1.27$, $p=0.21$], # syllables [Syn/ID: $|t| <1$, Rel: $|t| <1$, Unrel: $|t| <1$], and #phonemes [Syn/ID: $t(130)=-1.36$, $p=0.18$, Rel: $|t| <1$, Unrel: $t(130)=-1.32$, $p=0.19$]. Highly associated word pairs were not included (like mouse-CHEESE), as confirmed via the Edinburgh Associative Thesaurus (Kiss, Armstrong, Milroy, & Piper, 1973). In cases involving Unknown word primes, Syn/ID, Rel and Unrel, was determined by its implied meaning from sentence context in which it had previously appeared.

An equal number of Nonword targets were also constructed so that the proportion of "Yes" and "No" lexical decision responses were equivalent. Nonwords were constructed using the ARC Nonword database (Rastle, Harrington, & Coltheart, 2002), and were selected to be pronounceable, and to contain between 4-7 letters.

In each version, each Known and Unknown prime was paired with two of three possible real word targets, and two nonword targets. The proportion of targets in each condition was: Nonwords=1/2, Syn/ID=1/6, Rel=1/6, Unrel=1/6. Known and Unknown prime was matched with the targets with equal frequency across versions. Table 1b includes examples of word pairs in the study.

Procedure:

Participants were tested in a soundproof, electrically-shielded chamber and were seated in a comfortable chair in front of a monitor. The experiment consisted of two interleaved tasks: sentence comprehension and priming.

In the sentence comprehension task, participants were instructed to read the sentence pairs for comprehension and to try to understand the sentences even when nonsense words appeared. The first sentence in each pair was presented in its entirety, and participants pressed a button to indicate that they were ready for the second. The second sentence was preceded by a series of crosses (500 ms duration with a stimulus-onset-asynchrony (SOA) varying randomly between 300-800 ms) to orient the participant toward the center of the screen. Sentences were presented one word at a time, each for 200 ms with a SOA of 500 ms. Participants were asked to minimize blinking and movement during sentences. The final target word appeared for 1400 ms.

In the priming task, participants were instructed to read every word that appeared on the screen and indicate with a button press if the target item (which always appeared in capital letters) was or was not a real word. Participants viewed two sets of prime/target pairs, and were given a 2500ms offset period to blink between pairs. Prime pair onsets were preceded by a set of fixation crosses that were randomly presented for 200-500ms. Immediately following the fixation cross, a prime word appeared for 200 ms, followed by an offset of 300ms, followed by the target word presentation for 200ms, and offset of 800ms. Participants provided a lexical decision response as soon as possible after each target word appeared in capital letters.

Table 1. Examples of sentences and word pairs

A) Context Sentence Pairs (Context Constraint / Word Type)	
High/ Known	Peter sat gaping at the centerfold. He asked his friend if he could borrow the MAGAZINE.
High/ Unknown	Peter sat gaping at the centerfold. He asked his friend if he could borrow the YERGE.
Low/ Known	The package was rectangular and heavy and suspiciously academic. Bianca was disappointed that her uncle was giving her a BOOK.
Low/ Unknown	The package was rectangular and heavy and suspiciously academic. Bianca was disappointed that her uncle was giving her a SHUS.

B) Word Pairs (prime – TARGET)	Syn/ID	Rel	Unrel
High/ Known	magazine-MAGAZINE	magazine - NOVEL	magazine-ACCIDENT
High/ Unknown	yerge – MAGAZINE	yerge – NOVEL	yerge-ACCIDENT
Low/ Known	book – BOOK	book – LETTER	book – ROAD
Low/ Unknown	shus – BOOK	shus – LETTER	shus – ROAD

Note: all word pairs were also paired with an equal number of pseudoword targets, not depicted in this table

The experiment consisted of 11 blocks of sentence/prime sets that were interleaved as follows. Participants read 12 sentence pairs, before completing the priming task consisting of 48 pairs, with primes being selected from the 12 immediately preceding sentence endings. Participants were given a break after each sentence/priming set.

In order to ensure that participants attended to the study sentences, participants were given a surprise old/new memory post-test containing 50 sentences that had appeared in the study, and 50 sentences that had not.

Electrophysiological recording:

Scalp potentials were continuously recorded from 26 geodesically arranged sites using an ElectroCap with tin electrodes and a left mastoid reference. Potentials were digitized at a sampling rate of 250 Hz and hardware bandpass filter of 0.1-100Hz with Grass Amplifiers. Impedances were kept below 5 kΩ.

Data analysis*:* Data were re-referenced offline to an average left and right mastoid. Trials contaminated by eye movements, blinks, excessive muscle activity, or amplifier blocking were rejected offline before averaging. ERPs were computed for epochs extending from 100 ms pre-stimulus onset to 920 ms post-stimulus onset. Averages of artifact-free ERP trials were computed for the target words in the four learning conditions (High/Known, High/Unknown, Low/Known, Low/Unknown) as well as to targets in all priming conditions (Syn/ID, Rel, and Unrel targets for each of the four main conditions High/Known, High/Unknown, Low/Known, Low/Unknown) after subtraction of the 100 ms pre-stimulus baseline

Table 2. Mean reaction times (ms) and mean percentage of correct responses for priming task.

	Real Word Primes		Novel Word Primes	
	Constraint		Constraint	
	High	Low	High	Low
% correct				
Syn/ID	99 (0.6)	99 (1.9)	97(6)	98(2.1)
Rel	97 (2.4)	93 (4.1)	94(4.3)	95(3.5)
Unrel	93 (6.8)	96 (3.2)	95(3.4)	94(3.8)
RT				
Syn/ID	512 (80)	488 (82)	543 (77)	553 (76)
Rel	568 (87)	561 (72)	567 (79)	570 (83)
Unrel	586 (79)	578 (75)	571 (75)	567 (79)

Note: Standard deviations are reported in parenthesis.

Results

Behavioral performance:

Participants made lexical decisions for words that were identical, related, or unrelated in meaning to a prime word. Mean accuracy and RTs are shown in Table 2. We did not statistically analyze accuracy since accuracy was near ceiling, with the lowest accuracy in any condition being 93%. For RT, A three factor repeated measures ANOVA on RT was carried out with factors of Word type (Unknown and Known) x Constraint (High and Low) x Prime relationship (Identical, Related and Unrelated). A main effect of Prime was found [$F(2, 46)=85.49$, $p< 0.0001$], with Tukey tests revealing that this effect was driven by faster responses to Identical targets than every other condition. No overall difference was found between Rel and Unrel conditions. There was also a main effect of Word Type [$F(1, 23)=11.94$, $p=0.002$] driven by faster responses to targets preceded by Known vs. Unknown words. An interaction of Prime x Type was also found [$F(2, 46)=29.2$, $p<0.0001$]. Follow-up Tukey tests revealed that this interaction was driven by targets that were preceded by Syn/ID Known words eliciting the fastest responses compared to other conditions. There were no other significant interactions. Although no significant three-way interaction was found, pairwise comparisons were conducted to examine the relationships between Syn/ID, Rel and Unrel meanings in each of the four prime conditions: Known/High, Unknown/High, Known/Low, and Unknown/Low. These analyses revealed that targets preceded by Known/High and Known/Low primes elicited faster RTs when preceded by a word identical in meaning, compared to a related or unrelated word. On the other hand, targets preceded by Unknown words did not elicit priming effects in any condition (all $p>0.05$).

ERP data: N400 amplitude

Context sentence endings*:* We analyzed ERP responses to sentence endings in four conditions: Known/High, Known/Low, Unknown/High and Unknown/Low. ERPs to sentence endings are shown in Figure 1. N400 mean amplitude was measured between 250-500ms post final word onset at four centro-parietal electrode sites (RMCe, LMCe, MiCe, MiPa) where N400 effects are typically largest. A two-factor repeated measures ANOVA with factors of Word Type (Known and Unknown) and Constraint (High and Low) revealed an effect of Word Type [$F(1,23)=28.85$, $p<.0001$] with Unknown word endings eliciting larger N400s than Known word endings. No other main or interaction effects were observed.

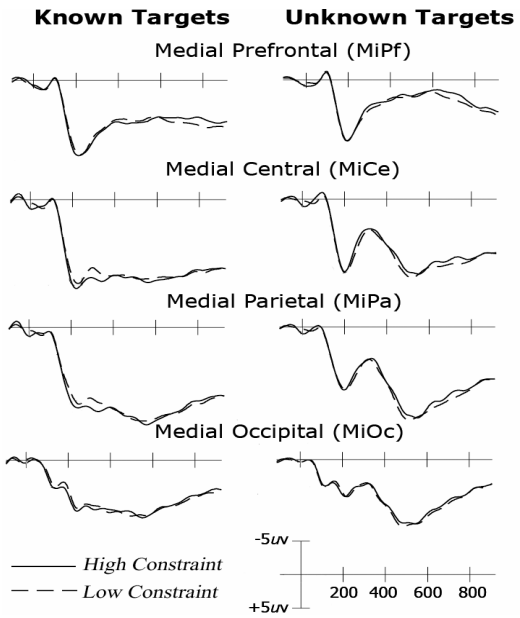

Figure 1. Grand average ERPs to known and unknown target words in context sentences at medial electrode sites.

Priming task: a shows ERPs to target words in the four main prime word conditions (Known/High, Known/ Low, Unknown/High, Unknown/Low). As can be seen from this figure, an effect of Target type is seen via modulation of the negative going peak from 250-500ms (N400) in all Prime conditions, except for Unknown/Low words. N400 mean amplitude was measured between 250-500ms post target word onset at four centro-parietal electrode sites (RMCe, LMCe, MiCe, MiPa) where N400 effects are typically largest (Figure 2b). A three-factor repeated measures ANOVA was conducted with factors of Prime-Type (Known or Unknown), Prime-Constraint (High or Low) and Target relationship (Sy/ID, Rel, Unrel), using Greenhouse-Geisser. univariate epsilon values

Table 3. F-values from pairwise ANOVAs comparing mean amplitude N400 to related, unrelated, and synonym/ID targets

		Syn/ID	Rel	Unrel
Known/High				
	Syn/ID	--	14.92**	30.22***
	Rel	14.92**	--	11.17**
	Unrel	30.22***	11.17**	--
Known/Low				
	Syn/ID	--	27.80***	23.69***
	Rel	27.80***	--	Ns
	Unrel	23.69***	ns	--
Unknown/High				
	Syn/ID	--	6.22*	32.24***
	Rel	6.22*	--	4.61*
	Unrel	32.24***	4.61*	--
Unknown/Low				
	Syn/ID	--	ns	Ns
	Rel	Ns	--	Ns
	Unrel	Ns	ns	--

* - $p < 0.05$, ** - $p < 0.01$, *** - $p < 0.0001$

This analysis revealed a significant effect of Word Type [$F(1,23)=5.4990$, $p=0.02$], with Unknown words eliciting larger N400 amplitudes than known words, and Target [$F(1.8922, 43.522)=32.439$, $p<0.0001$], with Syn/ID targets eliciting the smallest N400 amplitudes, but no main effect of Constraint [$F(1,23)<1$]. There was also an interaction of Constraint x Prime [$F(1,23)=6.29$, $p=0.02$]. No other interactions were significant. Preplanned pairwise repeated measures ANOVA comparisons were conducted to compare mean N400 amplitude between Rel, Unrel and Syn/ID targets in each of the four main Prime word conditions. The results of these comparisons are shown in Table 3. As seen from this table, significant priming effects were observed in all conditions, except for Unknown prime words that initially appeared in Low constraint contexts.

Discussion

This study explored the neural correlates of the rapid acquisition of recently experienced novel word meanings in adults' native language. Our goal was to understand the influence of sentential constraint on the integration of novel word meanings into the "mental lexicon" after only a single exposure. We measured behavioral and ERP responses in priming task to ask if the information that is rapidly integrated about novel word meanings includes information about a word's lexico-semantic relationships with other (known) words.

The behavioral (lexical decision) results did not reveal evidence of priming between novel words and related or synonymous targets. This result alone would suggest that no learning occurred regardless of sentential constraint. The electrophysiological results, however, support a different conclusion.

Known word primes produced N400 priming effects replicating a well-established result: smaller N400 amplitudes to target words preceded by identical or related words, relative to unrelated words. This was also the pattern for Unknown words (or perhaps more accurately, recently seen words) but only if it had initially appeared in a strongly constraining context. Semantic relatedness between an Unknown (novel word) prime and a real word target could only have been inferred from the sentence context in which that novel word previously appeared and apparently only strongly constraining contexts supported this inference.

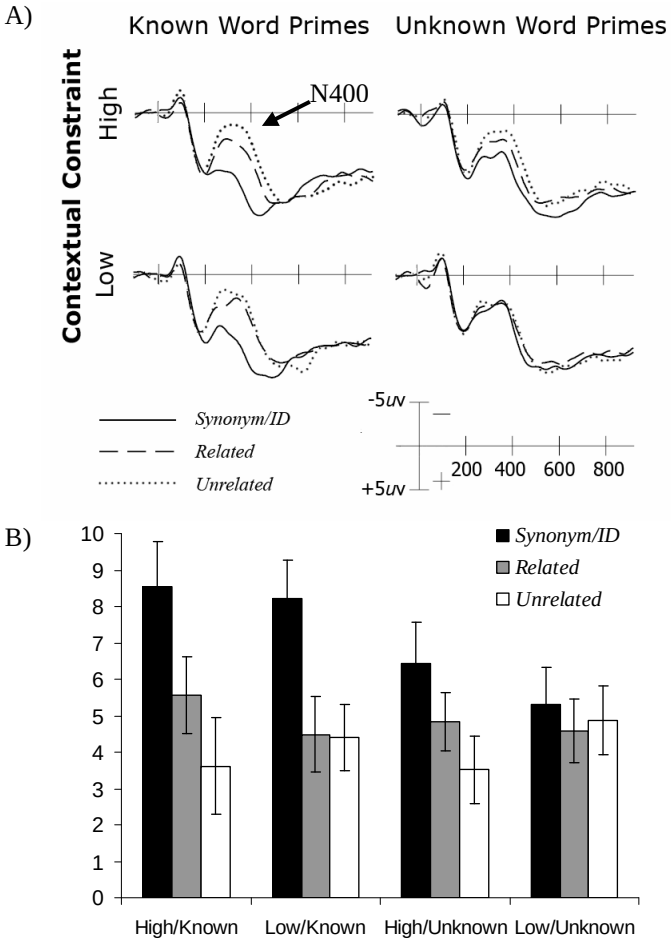

Figure 2. A) Grand average ERPs to target words in priming task at the vertex electrode (MiCE). B) N400 Mean amplitudes 250-500ms. Since the N400 is a negative going wave, larger N400 amplitudes are represented by smaller values on this figure.

Previous work has suggested that adults can integrate and organize information about word meanings after a few of weeks of second language instruction (McLaughlin et al., 2004; Stein et al., 2006), and even more rapidly in adult's first language, such as after only an hour of study of word definitions (Perfetti et al., 2005) or after three presentations in sentential context (Mestres-Misse et al., 2006). Our results extend these findings to show that in some cases a single exposure of a novel word in a strongly constraining sentence context is sufficient to convey significant information about its meaning to support semantic priming, and that there is a very fast neural process which enables the integration and retention of this information over at least a several minute delay. We add to a growing body of evidence that the rapidly acquired information about novel words includes

information not only about its usage in sentences but also about its meaning.

More generally, this paradigm suggests a novel method to examine the impact of sentential context and constraint on word processing. Further research will be necessary to extend these findings to other aspects of word meaning and knowledge, and to determine how long such information about a word's usage and meaning is retained and is effective.

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