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Word Wars: The Role of Form and Semantic Encoding in Implicit and Explicit Recognition of Nouns and Verbs

Encoding word form and semantic information is critical for integrating new words into the lexicon. Factors like encoding context and word class impact memory traces and, thus, recognition of new words. This study investigated how encoding form and semantic information in incidental contexts influences later explicit and implicit recognition of novel nouns and verbs. Across two experiments (Noun: $n = 31$; Verb: $n = 23$), although explicit semantic encoding did not facilitate behavioral recognition, neural measures (mismatch negativity [MMN], N400) revealed distinct implicit processing patterns for each word class. MMN results indicated word form encoding for nouns but not verbs. N400 results showed that nouns with explicitly identified meanings required more effortful processing, whereas most previously encountered verbs showed evidence of semantic encoding regardless of meaning identification. These findings provide insights into mechanisms underlying word learning and word recognition and illustrate how lexical representation development differs across word classes.

Keywords: recognition, semantics, N400, MMN, mismatch negativity, word form

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An individual's vocabulary size increases throughout their lifetime and is estimated to reach over 17,000 words in adulthood (Goulden et al., 1990; Zechmeister et al., 1995). Each word is stored in long-term memory (e.g., the lexicon) as a lexical representation consisting of information pertaining to the word's phonological and/or orthographic form, syntactic features (e.g., word class), and semantic features (i.e., the word's meaning; Leach & Samuel, 2007), at a minimum. Acquiring this information about a new word is a dynamic, incremental process, typically requiring multiple instances of abstracting these relevant features from the surrounding linguistic (i.e., oral, written) and/or environmental contexts and encoding and integrating the relevant linguistic information to form a lexical representation (e.g., Frishkoff et al., 2008; Fukkink, 2005; Gaskell & Dumay, 2003; Leach & Samuel, 2007; Storkel, 2011). These lexical representations' memory traces vary in strength as a result, and are activated during future encounters with and productions of the word (Durso & Shore, 1991; Frishkoff et al., 2008, 2009; Leach & Samuel, 2007; Storkel, 2011). There is substantive literature examining the impact that different features of the lexical information provided (e.g., phonological/orthographic word form, etc.) and the context the word is introduced in (e.g., highly constraining linguistic contexts) have upon abstraction of lexical information and subsequent encoding, retention, and activation of new lexical representations (e.g., Balass et al., 2010; Bolger et al., 2008; Frishkoff et al., 2011; Momsen & Abel, 2021; Shore & Kempe, 1999; Takashima et al., 2014, 2017). What is less well understood is whether differences during encoding influence later recognition of new words and, in particular, whether these effects differ across word classes.

Word recognition tasks, such as reporting whether each word in a list was previously encountered, are a common way of assessing the strength of a new lexical representation's memory trace. Adults can successfully recognize new word forms (i.e., orthographic and/or phonological forms with no semantic information) after one or more exposures in an encoding task (Dumay & Gaskell, 2007; Gaskell & Dumay, 2003; Leach & Samuel, 2007; Takashima et al., 2017). This ability to recognize words is improved when a new word form is explicitly paired with semantic information during encoding via an accompanying picture or definition (Balass et al., 2010; Takashima et al., 2014, 2017). Thus, the explicit addition of semantic information during encoding appears to enhance later recognition. However, when semantic information is provided in a less explicit manner, the effects of this semantic information on word recognition remain unclear.

In studies where the process of encoding a new word's meaning occurs in incidental contexts, such as requiring participants to infer the new word's meaning from the sentence(s) in which it is introduced (i.e., via an incidental encoding paradigm), the addition of semantic information seems to have no impact on immediate behavioral word recognition (Abel et al., 2020; Dumay et al., 2004). Importantly though, despite a lack of behavioral recognition directly following

the encoding task, participants in these studies still demonstrate recognition of the new words, either at a later time point or through more sensitive measures. For instance, following a one-day and seven-day delay after encoding, Dumay et al. (2004) found better behavioral recognition of word forms when semantic information was incidentally provided during encoding compared to word forms where no semantic information was provided. Using electroencephalography (EEG), Abel et al. (2020) identified that, immediately following the encoding task, school-aged children showed neural sensitivity to word forms that had been presented in semantically informative incidental contexts during encoding compared to word forms presented with inconsistent semantic information during encoding. Critically, this neural sensitivity was present despite children performing at chance on a behavioral recognition task administered directly following the encoding task, suggesting implicit recognition of word forms is possible when presented in incidental encoding contexts, even in the absence of explicit, behavioral recognition.

As Abel et al.'s (2020) study exemplifies, EEG offers a temporally precise way of examining implicit processes underpinning word recognition in real time even without explicit behavioral responses. Two event-related potential (ERP) components, the mismatch negativity (MMN) and the N400, are well-suited for detecting changes in the neural signal thought to underlie the processes that occur during word recognition. The MMN is a negative-going, frontally distributed ERP component that occurs between 30 and 170 ms after stimulus onset. The MMN is largely automatic and attention-independent in nature and is sensitive to differences in familiarity across a number of stimuli (Aleksandrov et al., 2020; Garrido et al., 2009; Näätänen et al., 1997; Shtyrov et al., 2010). In the traditional oddball paradigm, the MMN is more negative in response to infrequently presented, deviant stimuli versus frequently presented, standard stimuli. Thus, in this paradigm, a lack of familiarity with the stimuli is generally associated with a more negative deflection of the ERP. However, when comparing the MMN elicited by multiple types of deviants that vary by a specific feature, such as word form familiarity, more familiar deviants elicit a more negative MMN response than less familiar deviants (Aleksandrov et al., 2020; Jacobsen et al., 2005; Pulvermüller et al., 2001; Shtyrov et al., 2010). For example, research has demonstrated that real word deviants result in a more negative MMN than novel word deviants (Pettigrew et al., 2005), and similarly, recently learned words result in a more negative MMN than new words (Shtyrov et al., 2010). In the case of word form familiarity, this enhanced neural response is thought to reflect automatic activation of an experience-dependent, long-term memory trace for word forms (Hu et al., 2020; Pulvermüller et al., 2001; Shtyrov & Pulvermüller, 2002). Therefore, the MMN might not only reflect the acoustic change in speech stimuli, but also the initial, automatic stages of word recognition, namely lexical processing and word form familiarity (Pettigrew et al., 2005).

A complementary ERP component that is relevant to the study of word rec-

ognition is the N400. This component is characterized by a negative deflection of the ERP between 300 and 600 ms after stimulus onset and is largest over centro-parietal sites with a left hemisphere bias (Federmeier & Kutas, 1999; Holcomb & Neville, 1991; Sereno et al., 2003; West & Holcomb, 2000). It has been well-established that the N400 reflects automatic semantic processing, occurring regardless of whether an individual consciously perceives a stimulus (Kiefer, 2002; Kutas & Hillyard, 1980; Misra & Holcomb, 2003). To process semantic information, the encoded semantic information must be automatically activated and accessed in long-term semantic memory, making the N400 an index of implicit recognition of a word's meaning. When limited semantic information is available, the memory trace for that semantic information is less robust, which typically results in more effortful semantic processing and is reflected by a more negative N400 response relative to words with a stronger semantic memory trace (Kutas & Federmeier, 2011). Thus, if insufficient semantic information is abstracted from context and/or it is not adequately encoded and mapped to the word form, the N400 will usually reflect the negative effects of these failures on the early, automatic semantic processing stage of word recognition.

Together, these ERP components are useful measures for understanding the roles word form and semantic information play in behavioral word recognition. Further, because these ERP components reflect automatic processes, separable from behavioral performance, they can also provide insights into the formation of lexical representations that are not yet robust enough to support behavioral demonstrations of recognition. This is particularly important given the evidence that immediate behavioral word recognition is not facilitated by the addition of semantic information in incidental encoding paradigms (Abel et al., 2020; DuMay et al., 2004), but neural signs of recognition still occur (Abel et al., 2020). As such, these ERP components can help us tease apart the impact of word form and semantic information on both implicit and explicit word recognition processes.

Word class differences between nouns and verbs have also been shown to impact word recognition. Behavioral studies have demonstrated that nouns, compared to verbs, are learned at a faster pace, with less effort, and at an earlier age (e.g., Bornstein et al., 2004; Gentner, 1981; Mätzig et al., 2009; Piccin & Waxman, 2007; Riches et al., 2005). Even adults demonstrate this “noun advantage,” consistently providing more accurate and faster responses for object nouns than action verbs in picture naming and sentence completion tasks (Colombo & Burani, 2002; Druks, 2002; Federmeier & Bates, 1997; Huttenlocher & Lui, 1979; Kauschke & von Frankenberg, 2008; Mätzig et al., 2009; Szekely et al., 2005). Few studies have investigated word class differences specifically with respect to word recognition, but the available studies have found that nouns are consistently recognized more frequently than verbs (Earles & Kersten, 2017; Engelkamp & Zimmer, 1995; Kersten & Earles, 2004; Mohr et al., 1989; Reynolds & Flagg, 1976).

The reason for these learning and recognition differences between nouns and verbs is commonly attributed to the fact that verbs are inherently linked to other words and their meanings are more dependent on context (Gentner & Boroditsky, 2001; Gentner & France, 1988; Kersten, 1998, 2003; Kersten & Earles, 2004; Kintsch, 2001). Specifically, verbs require arguments (e.g., *swim* requires some subject, such as *fish*; Huttenlocher & Lui, 1979; Vigliocco et al., 2004) and are more likely to have multiple meanings (i.e., be polysemous; e.g., *break* means “disobey” in *break the law* but “separate into multiple pieces” in *break the vase*; Gentner, 1981; Jenkins & Dixon, 1983; Kintsch, 2001; Levin, 1993), with the relevant meaning determined by the linguistic and/or environmental context. Contrastively, nouns do not require arguments and their meaning is typically more consistent across contexts (Gentner & Boroditsky, 2001; Gentner & France, 1988). Thus, verbs often entail increased processing demands compared to nouns, especially regarding semantic information.

While the studies mentioned above utilized behavioral methods to compare noun and verb word recognition, there is also evidence of differential neural processing of each word class. The MMN reflects greater sensitivity to differences between standard and deviant nouns compared to verbs (Hasting et al., 2008; Jacobsen et al., 2021). Additionally, the N400 peak latency is approximately 23 to 32 ms earlier for nouns than verbs (Gomes et al., 1997; Khader et al., 2003; Rösler et al., 2001) and the peak amplitude is generally greater for nouns compared to verbs (e.g., Lee & Federmeier, 2006; Rösler et al., 2001; but see Khader et al., 2003). These differences indicate faster and more robust processing of the meanings for nouns versus verbs. However, when examining differences between novel nouns and novel verbs (i.e., pseudowords), the difference in peak amplitude is reversed, reflecting the additional effort required to encode the meanings of novel verbs compared to novel nouns (Federmeier et al., 2000). Taken together, these findings suggest that neural differences may subserve behavioral differences in how nouns and verbs are processed.

The present study aims to add to our understanding of word class, incidental encoding, and word recognition by investigating the recognition of novel nouns and verbs after exposure to both word form and semantic information in an incidental encoding task. In the incidental encoding task, novel word forms were introduced in sets of three sentences that supported the identification of the one-word target meaning for the novel word. Directly following the incidental encoding task, participants completed a two-alternative forced-choice (2AFC) recognition task, the task of interest for this study. In the 2AFC recognition task, participants were asked to indicate whether the novel word they heard was one they had encountered previously in the incidental encoding task (i.e., old), or if the novel word was one they had not been exposed to previously (i.e., new). We examined both behavioral and neural (i.e., MMN and N400) indicators of word recognition during the recognition task.

We have three predictions for this study:

1. Across word classes, identifying meaning during encoding will facilitate later behavioral recognition of the novel words. This prediction is supported by prior evidence that the combination of semantic information with a word form during the encoding phase facilitates better behavioral recognition than exposure to the word form alone. Even though evidence suggests that recognition is weaker when semantic information is incidentally—rather than explicitly—provided, that evidence comes from studies that considered whether there was merely an opportunity for form-meaning mapping to occur, not whether form-meaning mapping actually occurred. Here, we focus on the latter; specifically, whether successful explicit form-meaning mapping facilitates recognition. Because nouns consistently result in better recognition and increased processing demands are observed during recognition of verbs, we also predict participants will be more accurate in their behavioral recognition of novel nouns compared to novel verbs.

2. We predict that, across word classes, there will be a more negative MMN during recognition of novel words that were previously encountered in the encoding task (regardless of whether meaning was explicitly encoded) compared to new novel words. This prediction is based on the evidence that the MMN is more negative for familiar word forms compared to unfamiliar word forms, even in the absence of semantic information. Importantly, this evidence comes from comparing MMN responses to multiple types of deviant stimuli, rather than contrasting MMN responses to deviant stimuli with those to standard stimuli. Given that our paradigm does not allow for any stimuli to be standard or deviant, basing our predictions on comparisons of deviant stimuli is more appropriate. Furthermore, we do not predict any word class differences in the MMN as what distinguishes nouns from verbs relates primarily to features other than word form.

3. Across word classes, the N400 amplitude during recognition will be attenuated for novel words in which meaning was successfully encoded (based on behavioral performance in the encoding task) compared to novel words where no meaning was encoded (according to behavioral performance in the encoding task). The N400 reflects the ease of semantically processing a stimulus, and processing the meaning of a word with semantic information encoded should be easier than a word that lacks such information. Given that verbs place higher demands on semantic processing than nouns, we predict that verbs will elicit a larger N400 effect than nouns.

Experiment 1: Nouns

Method

Participants

Fifty-one adults participated in this experiment. Twenty participants were excluded from analyses due to: the demonstration of a handedness bias (details

below; $n = 1$), bilingual status ($n = 15$), or technical issues ($n = 4$). The final participant group included 31 right-handed, normal-hearing, monolingual English-speaking adults (2 males), ranging in age from 18.00 to 29.69 years ($M = 21.25$, $SD = 2.64$). Exclusionary criteria included a history of language delays or disorders; a history of significant neurological conditions (i.e., central nervous system diseases, high fevers, seizure disorders, traumatic brain injury, cerebral vascular accident, tumors, or learning disabilities); use of alcohol, controlled substances, and/or medications other than over-the-counter analgesics and contraceptives within 24 hours prior to testing; and lack of right-handed dominance according to the Edinburgh Handedness Inventory (Oldfield, 1971). Participants were recruited from undergraduate courses in Speech, Language, and Hearing Sciences at San Diego State University. All participants gave informed consent in accordance with the Institutional Review Board of San Diego State University and received academic course credit for participation.

General Procedure

There were two primary experimental tasks that all participants completed in a fixed order: 1) an incidental encoding task whereby participants were exposed to both word form and semantic information for novel words (Encoding Task) and 2) a 2AFC word recognition task (Recognition Task). Behavioral and EEG data were collected during both tasks. Before starting the Encoding Task, participants were informed that the Recognition Task would follow, motivating them to encode the novel words they encountered. Prior to completing these tasks, participants completed a brief nonword repetition task (Dollaghan & Campbell, 1998) to statistically control for phonological working memory, as this ability is known to be associated with word learning success (Gathercole, 2006). EEG data collection set up separated the Nonword Repetition Task from the experimental tasks, thus minimizing any interference effects.

Nonword Repetition Task

The Nonword Repetition Task (Dollaghan & Campbell, 1998) was administered to measure phonological working memory. In this task, participants heard 16 novel words (nonwords) ranging from one to four syllables (four words per syllable length; see Table A1) and were instructed to repeat each word aloud as accurately as possible immediately after hearing it. The novel words were designed to follow English phonotactic rules while avoiding resemblance to real words, preventing reliance on existing vocabulary. Each novel word was presented once via an audio recording of a female speaker producing the word. Responses were recorded and scored for accuracy, operationalized as the percentage of correctly reproduced consonants.

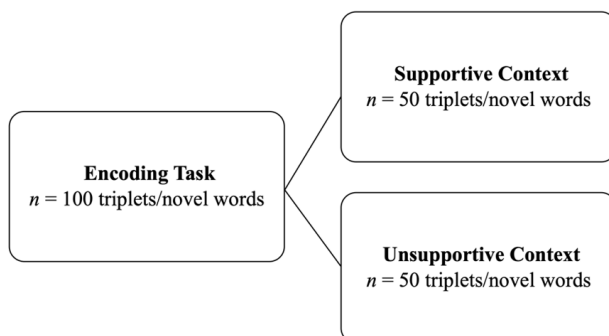
Encoding Task

Stimuli. Stimuli for the Encoding Task included 100 sets of three sentenc-

Table 1*Example Stimuli for the Encoding Task for Experiment 1*

Sentence Presentation	Supportive Context (target word: <i>face</i>)	Unsupportive Context (no target word)
1	He looks just like you in the <i>deav</i> .	Before you get food, grab a <i>pieg</i> .
2	Those twins look different in the <i>deav</i> .	The cake was decorated with a <i>pieg</i> .
3	She wears a lot of makeup on her <i>deav</i> .	When I sit there, I can see the <i>pieg</i> .
Scoring Examples		
Meaning Identified	Face, Eyes, Picture	N/A
No Meaning Identified	No meaning	N/A

Note. Stimuli consisted of sentence triplets in which all three sentences ended with the same CVC novel word. In the Supportive Context, the novel word replaced the same early acquired noun target word in all three sentences of the triplet and the sentences increased in cloze probability across the triplet. In the Unsupportive Context, which served as a control condition, the novel word replaced a different early acquired noun in each of the triplet's three sentences, resulting in no target word, and the sentences were all low cloze probability. Participants' responses to stimuli from the Supportive Context were classified offline for meaning identification, disregarding response accuracy.

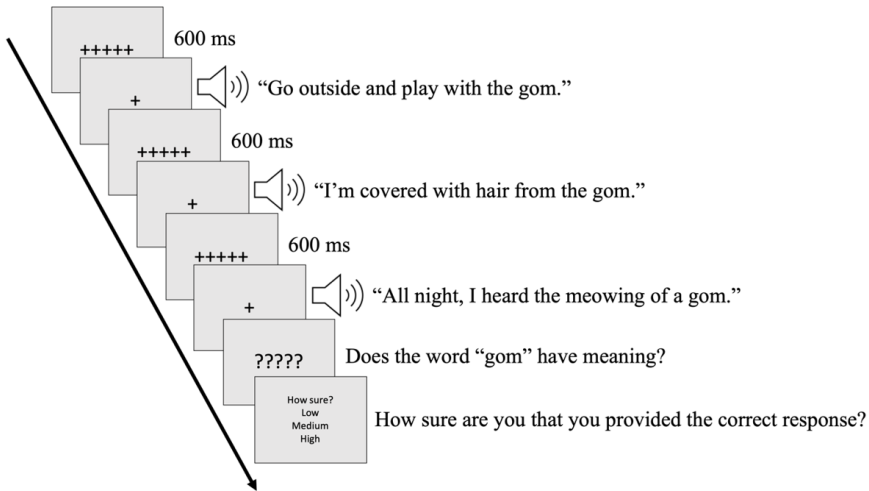
Figure 1*Breakdown of the Number of Stimuli per Condition for the Encoding Task*

Note. Each participant encountered a total of 100 different novel words in the Encoding Task, 50 of which were presented in the Supportive Context and 50 of which were presented in the Unsupportive Context (control condition).

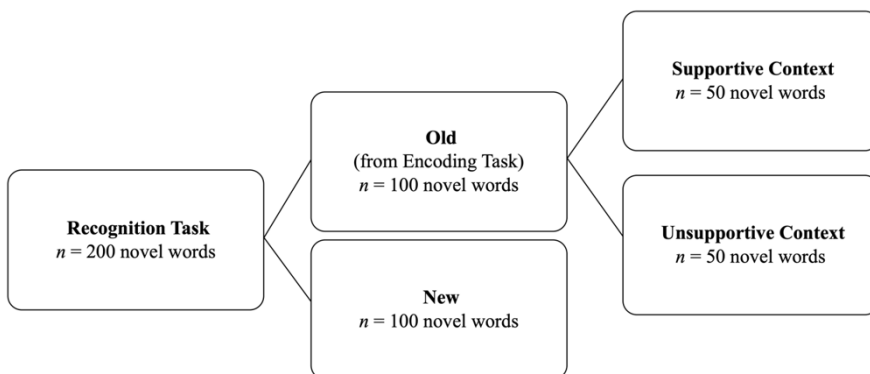
es, or sentence triplets, for a total of 300 sentences. Sentences were six to nine words in length with the final word of the sentence being the target word, which was an early acquired noun (Fenson et al., 2007). Words preceding the target word were a determiner (i.e., *a, the*) or possessive pronoun (i.e., *my, your, his, her, its*). Target words were replaced with a novel word drawn from a pool of 200 monosyllabic novel words that followed the phonotactic rules of Standard American English and were initially selected from a corpus of consonant-vowel-consonant (CVC) sequences (Storkel, 2013; see Tables A2 and A3 for a list of the novel words used). None of the novel words began with /s, ʃ/, or the same word-final sound of the word preceding the novel word (e.g., novel words that were preceded by *can* did not begin with /n/) to avoid coarticulation effects. The same novel word was used for each of the three sentences of a sentence triplet but varied across the 100 triplets (see Table 1 for examples), resulting in exposure to a total of 100 different novel words. None of the novel words from the Nonword Repetition Task appeared in the Encoding Task, and most stimuli in the Nonword Repetition Task differed substantially from those in the Encoding Task by syllable length (see Tables A1, A2, and A3).

Fifty of the 100 sentence triplets were constructed to support the identification of the single target meaning for the novel word (Supportive Context; see Figure 1 for pictorial representation of the breakdown). This was done by all three of the sentences of the triplet ending with the same target word and each sentence increasing in cloze probability across the triplet (Low: $M = 4.11$, $SD = 6.04$; Medium: $M = 40.60$, $SD = 10.17$; High: $M = 87.85$, $SD = 11.19$). Thus, the sentences became increasingly more semantically constraining and supportive of the single target word's meaning with each successive sentence (see Table 1 for examples). The remaining 50 sentence triplets were constructed to not support meaning identification for the novel word (Unsupportive Context; see Figure 1 for pictorial representation of the breakdown and Table 1 for examples) and were only included to control for repeated exposure. This was achieved by each sentence of the triplet having a different target word and all sentences having low cloze probability ($M = 18.32$, $SD = 17.85$). Cloze probability was determined via a separate norming task with 238 adults and was calculated as the proportion of participants who accurately provided the target word in a sentence with the final word removed (see Abel et al., 2015 for details).

Novel words appearing in the sentence-final position were counterbalanced across orders such that, over the course of 16 orders, they appeared in both the Supportive Context and Unsupportive Context, consequently serving as their own controls. Within a single order, novel words only ever appeared in one of the two contexts. All sentences were spoken at a natural pace with natural intonation by an adult female native English speaker and audio-recorded in a soundproof room to simulate naturalistic and optimal listening conditions (Length: Supportive Context: $M = 2,441.38$ ms, $SD = 362.80$ ms; Unsupportive Context: $M = 2,582.27$ ms, $SD = 396.29$ ms).

Figure 2*Stimulus Sequence of the Encoding Task Procedure.*

Note. Each sequence consisted of three auditorily presented sentences interleaved with 600 ms of silence and ended with two test questions verbally provided by a researcher. The visual stimuli of each trial merely directed attention and indicated trial progression.

Figure 3*Breakdown of the Number of Stimuli per Condition for the Recognition Task*

Note. Each participant heard a total of 200 different novel words during the Recognition Task, 100 of which were the 100 novel words that they had encountered previously in the Encoding Task (50 presented in the Supportive Context and 50 presented in the Unsupportive Context), and 100 of which they encountered for the first time in the Recognition Task.

Procedure. The Encoding Task was adapted from Abel et al.'s (2018, 2020) study of incidental word learning from context in children and Mestres-Missé et al.'s (2007) study investigating incidental word learning from context in adults. Participants were seated in a dimly lit, soundproofed room approximately three feet away from a computer display and two speakers. The participants listened to the sentence triplets and, following each triplet, were asked two test questions: 1) does the novel word have meaning and, if so, what is it? and 2) how sure are you that you provided the correct answer (low, medium, high)? After explaining the task, the experimenter conducted two practice trials (one trial of the Supportive Context and one trial of the Unsupportive Context), making participants aware that some words had a meaning and some did not, and providing feedback and repetition as necessary. No feedback or repetition was provided during the test trials. A researcher sat in the room with the participant to administer the task and record the participants' responses online.

Each stimulus sequence began with a row of crosses appearing on the monitor for 600 ms, followed by a single fixation cross displayed as the spoken sentence was presented at a comfortable volume. After the sentence, participants saw another row of crosses, indicating that they could press a button to move on to the next trial. After the third sentence in each sentence triplet, a row of question marks was displayed that indicated that the researcher was to present the test question about the meaning of the novel word. Once the participants responded to the first test question, the participants were instructed to press a button to proceed to the next screen, which displayed the text, "How sure? / Low / Medium / High." This screen indicated that the researcher was to present the test question about the participant's confidence level (see Figure 2 for a pictorial representation of the stimulus sequence).

To examine how encoding word form and semantic information during the Encoding Task influences later recognition, we focused solely on the responses to novel words from the Supportive Context; responses to novel words from the Unsupportive Context were not included in our analyses. Participants' responses were classified offline as Meaning Identified or No Meaning Identified following Abel et al.'s (2018) methods for data analysis. A response was classified as Meaning Identified if the participant provided any meaning for the novel word and the response was classified as No Meaning Identified if the participant responded that there was no meaning for the novel word. Response classification disregarded the accuracy of the response (i.e., whether the meaning provided matched the target word or the participant correctly claimed that the novel word had no meaning). Scoring examples are provided in Table 1.

Recognition Task

Stimuli. Stimuli for the Recognition Task included novel words previously encountered in the Encoding Task (old; $n = 100$, 50 from the Supportive Context and 50 from the Unsupportive Context) and new novel words that had not been

presented at all in the previous Encoding Task (new; $n = 100$; see Figure 3 for pictorial representation of the breakdown). The novel words for the Recognition Task came from the same pool of 200 novel words used in the Encoding Task (see Tables A2 and A3). All novel words were produced by the same speaker who produced the Encoding Task stimuli and were recorded in the same way (Length: $M = 576.93$ ms, $SD = 121.47$ ms). The presentation of novel words as old or new was counterbalanced across orders so that they served as their own controls.

Procedure. After completing the Encoding Task, participants were given a short break before beginning the Recognition Task. Prior to beginning the Recognition Task, the experimenter explained the task but there were no training trials. No feedback or repetition was provided during the test trials.

A trial in the Recognition Task included a row of crosses that was displayed on the monitor for 600 ms, followed by a single fixation cross displayed with the auditory presentation of the novel word at a comfortable volume. Following the novel word, a row of question marks was displayed in the middle of the monitor which cued the participant to make their response and remained until the response was provided (see Figure 4 for pictorial representation of stimulus sequence). Participants responded by indicating whether they believed the novel words were old (i.e., previously encountered in the Encoding Task) or new (i.e., not previously encountered in the Encoding Task/encountered for the first time in the Recognition Task) using a response box with two buttons. One of the buttons was marked with a smiling face emoticon and one was marked with a frowning face emoticon. Participants were instructed to press the smiling face button for old novel words and press the frowning face button for new novel words. The button assignments were counterbalanced across conditions to control for hand bias. Guided by previously used criteria (Abel et al., 2020), participants who demonstrated a bias for one button by providing one type of response (new or old) for more than 90% of their responses and simultaneously providing the other type of response for less than 10% of their responses were excluded from analyses.

Related to the research questions, old novel words were further separated offline into those with Meaning Identified during the Encoding Task and those with No Meaning Identified during the Encoding Task. Recognition performance was then categorized by word status (i.e., Meaning Identified, No Meaning Identified, New) and accuracy (i.e., Correct Recognition, Incorrect Recognition), yielding five conditions of interest: Meaning Identified, Correct Recognition; Meaning Identified, Incorrect Recognition; No Meaning Identified, Correct Recognition; No Meaning Identified, Incorrect Recognition; and New, Correct Recognition. These conditions provide insight into the recognition of words with recently explicitly encoded meanings, failed recognition of words with recently explicitly encoded meanings, recognition of recently encountered words without explicitly encoded meanings (i.e., likely only encoded forms), failed recognition of recently encountered words without explicitly encoding meanings (i.e., possibly no

encoded information), and recognition of new words, respectively. Comparing these five conditions allowed us to isolate the effect of encoding form and/or meaning on later recognition.

Behavioral Analysis

The present study investigates the effect of encoding form and meaning on both implicit and explicit recognition of novel words. To explore the impact on *explicit* recognition, we examined participants' behavioral performance in the Recognition Task, quantifying performance using A' . A' was computed for each word status following the formulas in Stanislaw and Todorov (1999). This nonparametric sensitivity measure from signal detection theory accounts for response bias and is robust to violations of normality and equal variance (Stanislaw & Todorov, 1999), which were present in some of our data. Furthermore, it is widely used to quantify signal detection in 2AFC tasks, particularly in memory research (e.g., Abel et al., 2020; Mohr et al., 1989). A' reflects the proportion of true positive responses (hits) relative to false positive responses (false alarms), yielding values ranging from 0.5 (chance performance) to 1.0 (perfect performance; Stanislaw & Todorov, 1999).¹ For the Recognition Task, hits were defined as correctly identifying a Meaning Identified or No Meaning Identified word as old (i.e., previously encountered in the Encoding Task). False alarms occurred when a new word was incorrectly identified as old (Meaning Identified or No Meaning Identified).

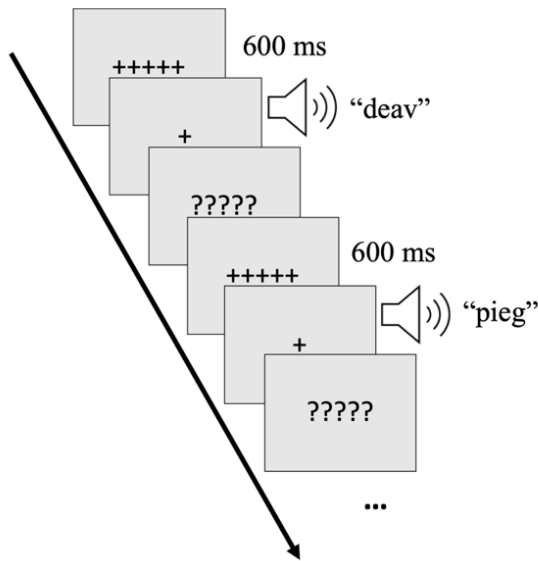
We subjected these A' values to a linear mixed-effects regression model that was fit using maximum likelihood estimation via the lme4 package in R (version 1.1-35.1; Bates et al., 2015), with the intercept centered at chance performance to test whether A' differed from chance. Following the comparison to chance performance, to address our primary interest of the impact of meaning identification on explicit recognition, we directly compared A' values for Meaning Identified versus New and No Meaning Identified versus New using a separate linear mixed-effects model.

Final models were achieved by first constructing a maximal model that included the fixed effects of interest, all measured covariates (i.e., phonological working memory, age, and gender), and the maximal random effects structure justified by the study design (per guidelines provided by Barr et al., 2013, and Brauer & Curtin, 2018). When this maximal model did not converge or resulted in a (near) singular fit, guided by Bates et al.'s (2018) recommendations, we iteratively reduced model complexity by removing variance components estimated at or near zero until convergence was achieved and/or singularity was no longer detected. A priori contrasts were used with a family-wise type I error rate set at an alpha of 0.05.

¹ Values can be less than 0.5, with a minimum possible value of 0, due to sampling error or response confusion (Stanislaw & Todorov, 1999).

Figure 4

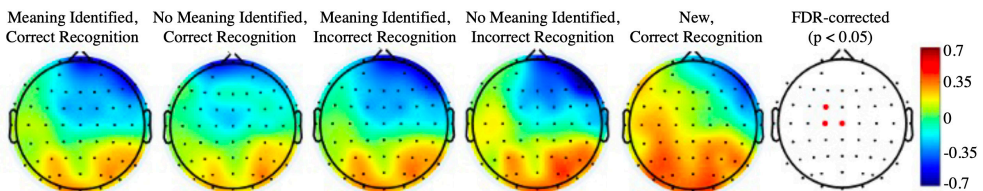
Stimulus Sequence for the Recognition Task Procedure.



Note. Each trial consisted of 600 ms of silence followed by an auditorily presented novel word and ended with a response opportunity. The visual stimuli of each trial merely directed attention and indicated trial progression.

Figure 5

Scalp Maps of Nouns Representing Significant Differences between All Conditions from 30 to 170 ms after Target Word Onset.



Note. Increases in ERP Amplitude are Represented in Red, and Decreases in ERP Amplitude are Represented in Blue. Electrodes Identified as Significant by the Cluster-Based Permutation Test are Highlighted in Red on the Far Right Scalp Map (FDR-Corrected p -Values < .05).

EEG Acquisition

While completing both tasks, each participant wore a 64 silver/silver-chloride electrode cap (Neuroscan Quickcap). Continuous data were collected throughout the experiment using a NeuroScan SynAmps2 amplifier and Scan 4.3.2 software sampled at 1 kHz with impedances typically below 5 k Ω . Electrodes were placed using the International 10-20 electrode placement standard with one electrode placed above and one below each participant's left eye to monitor ocular motor movement. Impedances were monitored by researchers throughout the study.

EEG Pre-Processing

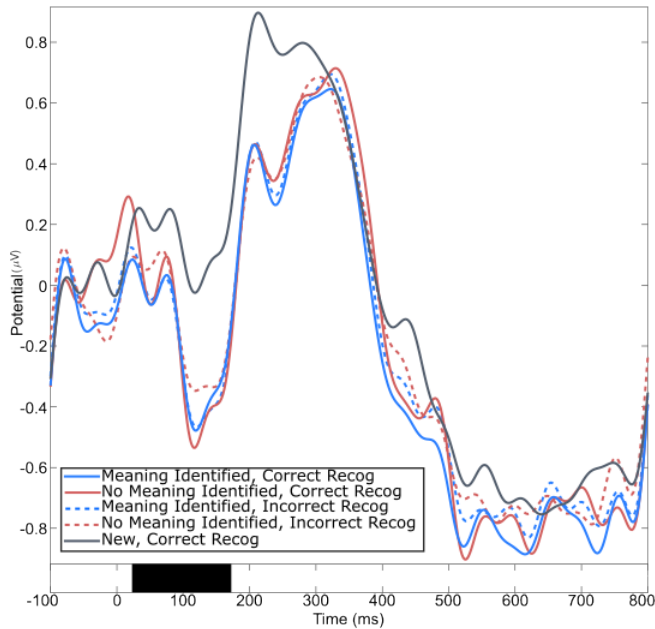
EEG data were analyzed using the EEGLab toolbox of MATLAB (Delorme & Makeig, 2004). Data were resampled offline at 500 Hz, high-pass filtered at 0.1 Hz, and low-pass filtered at 50 Hz. For electrodes with large impedances, data for the electrode was interpolated to yield 62 data channels for each participant (channels interpolated: $M = 1.45$, $SD = 0.87$). EEG data were also re-referenced to temporoparietal electrodes (TP7, TP8) to minimize error found in averaging across electrodes. Blocks of EEG data with visually detectable artifacts were manually identified and removed by trained researchers. Independent components analysis (ICA; Delorme et al., 2001) was run on all EEG data to minimize the effects of ocular motor movement on brain data. Components related to eye and head movement were manually removed from each participant (rejected components: $M = 1.67$, $SD = 0.82$). Data was then epoched from 500 ms before to 1000 ms after the presentation of the novel word. Epochs that were contaminated by artifacts (i.e., contained abnormal thresholds [upper limit: 75 μ V; lower limit: -75 μ V], abnormal trends [max slope: 50 μ V/epoch], improbable data [single channel limit of 5], and/or abnormal distribution [standard deviation of 5]) were rejected using ERPLab (Lopez-Calderon & Luck, 2014; removed epochs: $M = 11.97$, $SD = 9.72$).

ERP Analysis

To examine the impact of encoding form and semantic information on *implicit* recognition of novel words, we investigated changes in the MMN and N400 across the five conditions of interest from the Recognition Task. We defined the time windows and electrodes of interest by examining significant differences between our five conditions of interest using a Monte Carlo cluster-based permutation test within the EEGLab Toolbox (Oostenveld et al., 2011) of MATLAB (Groppe et al., 2011a, 2011b). This is done by first comparing every sample (channel, time) within each experimental condition using a t-test. All samples with t-values significant at an alpha of 0.05 are clustered into connected sets, based on their temporal and spatial adjacency. The cluster-level statistics are then calculated by taking the sum of the t-values within every cluster and determining the maximum cluster-level statistic. To then determine statistical significance

Figure 6

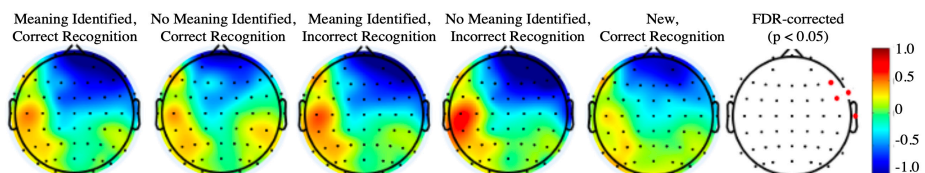
ERP Waveforms of Nouns Representing Significant Differences between All Conditions from 30 to 170 ms after Target Onset



Note. Significant differences between 30 and 170 ms are highlighted by the black line along the x-axis. This ERP waveform is from the average of all electrodes identified as significant in the cluster-based permutation test.

Figure 7

Scalp Maps of Nouns Representing Significant Differences between All Conditions from 350 to 550 ms after Target Word Onset



Note. Increases in ERP amplitude are represented in red, and decreases in ERP amplitude are represented in blue. Electrodes identified as significant by the cluster-based permutation test are highlighted in red on the far right scalp map (FDR-corrected p -values < 0.05).

between groups, we applied the Monte Carlo method. Using the cluster-based test statistic identified by the previous analysis, the Monte Carlo permutation involves: 1) collecting EEG data for each of the experimental conditions, 2) drawing as many trials from each combined data set as there are conditions, and placing these additional trials within separate subsets (referred to as random partitioning), and 3) calculating the test statistic based on this random partition (i.e., the maximum of the cluster-level summed t -values). Steps 2 and 3 are repeated 500 times, based on data size and number of variables, and then random test statistics are compared to the observed test statistic. The permutation p -value is the proportion of partitions where the observed test statistic is larger than the value drawn from the permutation test statistic. Permutation accuracy can be quantified by means of the well-known confidence interval of its binomial distribution (Ernst, 2004; Maris & Oostenveld, 2007). Finally, we applied an FDR correction to control for multiple comparisons.

Results

Behavioral Results

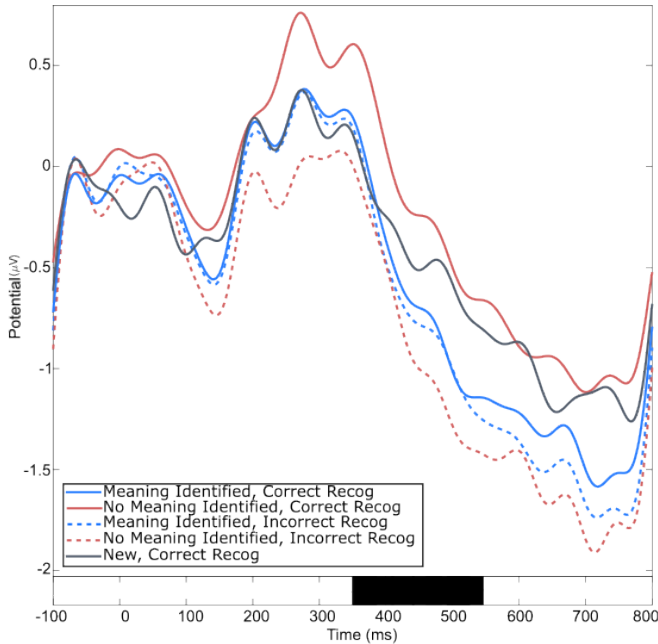
During the Encoding Task, adults identified a meaning for 87.74% of the novel nouns presented in the Supportive Context ($SD = 0.33\%$). In the subsequent Recognition Task, recall that participants categorized each novel word they heard as either “old” (i.e., previously encountered in the Encoding Task) or “new” (i.e., encountered for the first time in the Recognition Task). Analysis of A' values indicated that participants were significantly above chance at discriminating previously encountered novel nouns from new words ($M = 0.61$, $SD = 0.10$; $\beta = 0.09$, $SE = 0.04$, $t = 2.34$, $p = .03$). Turning to meaning identification, participants were not significantly above chance at discriminating novel nouns for which they *had* identified meanings during the Encoding Task from new words ($M = 0.60$, $SD = 0.11$; $\beta = 0.08$, $SE = 0.04$, $t = 1.94$, $p = .06$). However, their discrimination of novel nouns for which they had *not* identified meanings during the Encoding Task from new words was significantly above chance ($M = 0.63$, $SD = 0.18$; $\beta = 0.14$, $SE = 0.07$, $t = 2.07$, $p = .049$). Despite these differences, a direct comparison of A' values for nouns with versus without identified meanings (each relative to new words) revealed no significant difference ($\beta = 0.03$, $SE = 0.04$, $t = 0.67$, $p = .51$). For descriptive purposes, recognition accuracy by word status is summarized in Table A4.

ERP Results

Given the evidence that implicit differences in recognition may be present in the absence of explicit behavioral recognition, we explored whether the presence of changes in the underlying neural signal during recognition could be attributed to word form familiarity and/or semantic encoding. We focused our analyses on two ERP components: the MMN, which shows sensitivity to differences in

Figure 8

ERP Waveforms of Nouns Representing Significant Differences between All Conditions from 350 to 550 ms after Target Onset



Note. Significant differences between 350 and 550 ms are highlighted by the black line along the x-axis. This ERP waveform is from the average of all electrodes identified as significant in the cluster-based permutation test.

word form familiarity, and the N400, which reflects automatic semantic processing. Both analyses compared neural activity across the five conditions of interest from the Recognition Task (i.e., Meaning Identified, Correct Recognition; Meaning Identified, Incorrect Recognition; No Meaning Identified, Correct Recognition; No Meaning Identified, Incorrect Recognition; New, Correct Recognition).

The MMN analysis included data from 30 to 170 ms after stimulus onset. In this time window, the cluster-based permutation identified significant differences between conditions over left frontocentral electrodes (all significant corrected p -values were $< .05$; see Figures 5 and 6). Post-hoc pairwise comparisons indicated that novel nouns to which individuals were previously exposed (i.e., Meaning Identified, Correct Recognition; No Meaning Identified, Correct Recognition; Meaning Identified, Incorrect Recognition), except for those in which no meaning was identified and recognition did not occur (i.e., No Meaning Iden-

tified, Incorrect Recognition), resulted in a more negative waveform than newly encountered (and correctly recognized) words (i.e., New, Correct Recognition; see Figure A1). No other pairwise comparisons significantly differed.

The N400 analysis identified a second cluster between 350 and 550 ms after stimulus onset at right frontotemporal and frontocentral electrodes (all significant corrected p -values were $< .05$; see Figure 7 and 8). Post-hoc pairwise comparisons indicated that this effect was driven by a larger negativity for both conditions wherein meaning was identified (i.e., Meaning Identified, Correct Recognition and Meaning Identified, Incorrect Recognition) than novel nouns that had no meaning identified but were correctly recognized (i.e., No Meaning Identified, Correct Recognition; all significant corrected p -values $< .048$; Figure A2). Novel nouns for which no meaning was identified and that were incorrectly recognized (i.e., No Meaning Identified, Incorrect Recognition) also had a larger negativity compared to novel nouns for which no meaning was identified but were correctly recognized (i.e., No Meaning Identified, Correct Recognition). No other pairwise comparisons significantly differed.

Discussion

In the current study, participants were generally successful in their identification of a novel noun's meaning in the Supportive Context of the Encoding Task. Additionally, participants demonstrated explicit recognition by reliably behaviorally distinguishing previously encountered novel nouns from words that they had never encountered. However, contrary to our prediction that identifying a meaning for a word during encoding would facilitate later behavioral recognition of it, there was no difference in behavioral recognition of previously encountered novel nouns with an identified meaning and previously encountered novel nouns without an identified meaning. Thus, successfully explicitly encoding a meaning for the novel noun did not provide any advantage to later behavioral recognition of the word.

Our finding that explicitly encoding meaning did not facilitate immediate behavioral recognition is similar to those of previous research studies utilizing the same paradigm with younger participants (Abel et al., 2020). Some key differences between the current study and the past work is that, here, we focused our analysis on items that were only presented in a context that supported identifying a meaning for the novel nouns in the Encoding Task and separated the Recognition Task responses based on whether participants did or did not explicitly provide a meaning for those novel nouns during the Encoding Task. In contrast, Abel et al.'s (2020) analysis considered items presented in both contexts that were and were not supportive of identifying a meaning for the novel nouns in the Encoding Task and separated the Recognition Task responses by context in the Encoding Task, not participants' responses during that task. We expected that our focused analysis, which considered overt evidence of successful form-meaning mapping, would result in greater behavioral accuracy in recognizing the novel word forms

to which participants indicated they had mapped meaning. While we did not find that explicitly mapping form and meaning facilitated recognition, the lack of this effect for novel nouns is consistent with past work that took a broader approach to meaning identification (i.e., whether form-meaning mapping was supported by the encoding environment, not necessarily whether mapping occurred). Possible explanations (relevant to both experiments) for the poor behavioral recognition despite the narrower focus are provided in the General Discussion.

Nevertheless, as Abel et al.'s (2020) study revealed, a lack of behavioral recognition does not mean no recognition occurred whatsoever. Indeed, participants demonstrated neural signals of recognition in the current study. As predicted, participants demonstrated a more negative MMN for almost all novel nouns that they had previously encountered in the Encoding Task compared to the novel words they encountered for the first time in the Recognition Task. In fact, only the MMN for novel nouns where no form-meaning mapping or recognition explicitly occurred failed to differ from the MMN for newly encountered novel words. Thus, with the exception of novel nouns that showed no evidence of encoding, familiar word forms elicited an enhanced MMN response compared to unfamiliar word forms, nearly mirroring the behavioral recognition of old versus new words. This pattern held true regardless of whether the familiar word forms had explicitly encoded meanings. As such, our findings align with previous findings (Aleksandrov et al., 2020; Jacobsen et al., 2005; Pulvermüller et al., 2001; Shtyrov et al., 2010). Notably, finding this generally predicted pattern and relatively robust effect despite using a less traditional paradigm for eliciting and examining the MMN supplies further evidence that the MMN is an index of word form familiarity, as well as provides a novel avenue for additional investigation of the MMN using paradigms that are more ecologically valid than the oddball paradigm.

Given that the MMN is generally thought to be independent of attention (Aleksandrov et al., 2020; Garrido et al., 2009; Hu et al., 2020; Näätänen et al., 1997; Pulvermüller et al., 2001; Shtyrov et al., 2010; Shtyrov & Pulvermüller, 2002), we expected that the MMN would be unaffected by behavioral performance and previous meaning identification, simply becoming more negative for any previously encountered word form. Yet, the neural signal for novel nouns that both had no meaning identified and were incorrectly recognized later were indistinguishable from new novel words. Although null results must be interpreted with caution, given the converging behavioral evidence, this finding suggests no information was encoded in these instances—not even implicitly.

Using an incidental encoding paradigm may have revealed these nuanced effects of word form encoding that oddball paradigms are unable to elicit. For example, the Encoding Task's focus on identifying a meaning for the novel noun might have biased participants' attention to abstracting and encoding the word's semantic information as opposed to attending to and storing information related to the word's form, hindering their ability to develop a strong word-form memo-

ry trace in some instances (Abel et al., 2020). Thus, failure to identify a meaning might have sometimes resulted in a weak memory trace for both word form and semantic information. Since a weak memory trace would result in a reduced sense of familiarity, this could explain the lack of differences in MMN amplitude between newly encountered novel words and novel words where no form-meaning mapping or accurate recognition occurred. Additional studies are required to better understand how incidentally acquiring semantic information impacts word form familiarity as indexed by the MMN. Altogether, our MMN results suggest that participants at least implicitly recognized previously encountered novel nouns' forms when that information was encoded.

Encoding semantic information also impacted the neural signals of recognition as indexed by the N400. We had predicted an attenuated N400 effect for words that participants had identified a meaning for compared to words without an identified meaning. While we did find that these conditions differed, they did so in the opposite way than predicted. That is, novel nouns with an identified meaning elicited an enhanced N400 compared to previously encountered novel nouns without an identified meaning that were correctly recognized later. This finding suggests increased processing demands for the novel nouns for which participants identified a meaning, which is the condition in which we would expect facilitated, not hindered, semantic processing.

One explanation for our unpredicted N400 finding is that processing novel nouns with an identified meaning (regardless of behavioral recognition accuracy) might have required greater cognitive effort to overcome obstacles, like lexicosemantic competition, that were absent for words with no identified meaning. The N400 has been shown to reflect competition among words that are lexically and/or semantically associated (i.e., lexicosemantic associates), with (novel) words with more lexicosemantic associates leading to more negative N400 deflections (Laszlo & Federmeier, 2011). Because the novel words in this study shared meanings with existing words, they essentially served as synonyms or translations of real words. Consequently, identifying a meaning for a novel word could have also linked it to the lexicosemantic associates of its synonymous real word, creating multiple competitors that activated simultaneously when the novel word was later encountered. When no meaning was identified, there were no additional lexicosemantic associates with which to compete, simplifying the search within semantic memory. As such, sufficiently activating the lexical representations for the novel nouns with identified meanings required more effort than doing so for novel nouns without identified meanings. When the word forms did not have any meaning associated with them, recognition relied on alternate features (e.g., word form familiarity), allowing participants to recruit fewer cognitive resources for processing the word's meaning or dismiss the need for it altogether. Thus, encoding meaning increased the amount of cognitive effort involved at later recognition rather than lessening it.

Another interesting N400 finding was that there was a distinction between the

two conditions of novel nouns with no identified meanings. Specifically, among these novel nouns, those that were *incorrectly* recognized elicited a more negative deflection than those that were *correctly* recognized. This finding suggests that correctly recognized novel nouns with no identified meanings required less cognitive effort to process than their unrecognized counterparts. We interpret this finding to suggest that, in the cases with novel nouns with no identified meanings, for those that were later recognized, some semantic information may have been implicitly encoded, even though participants did not explicitly demonstrate it. Indeed, previous research shows that semantic information—although usually abstract, such as semantic attributes (Koriat et al., 2003)—can be encoded without explicit awareness (e.g., Brown et al., 2013; Durso & Shore, 1991; Frishkoff et al., 2010). Thus, it seems participants were not simply guessing at random for all the novel nouns with no identified meanings; some implicitly encoded semantic information may have guided participants when they correctly recognized these novel nouns.

This finding's pattern where encoding semantic information requires less processing contrasts with the initially discussed pattern where encoding semantic information requires more processing. However, if linked lexicosemantic associates introducing competition underlies increased processing when semantic information is specifically *explicitly* encoded, a speculative possibility is that those links are not immediately formed when the semantic information is *implicitly* encoded. As a result, the more typical N400 pattern, where semantic encoding facilitates semantic processing (e.g., Kutas & Federmeier, 2011), can emerge. Implicitly encoding semantic information would create a weaker memory trace than explicit semantic encoding, potentially contributing to the lack of lexicosemantic associate linking. A weaker memory trace could have also played a role in the difference between novel nouns without identified meanings that were correctly recognized and novel nouns with identified meanings. Further investigation is required to substantiate this possibility. Overall, these findings imply that even when novel nouns lack explicit meaning identification, some implicit semantic encoding may still occur.

Together, the behavioral, MMN, and N400 results indicate that while encoding semantic information does not facilitate explicit recognition of novel nouns, it does influence implicit recognition. A distinction between recognizing previously encountered novel nouns and new words was evident both behaviorally and via the MMN, suggesting that word form information had been encoded in most instances during the Encoding Task and supported both implicit and explicit recognition at the old/new level. In addition, while behavioral recognition was unaffected by explicit semantic encoding (or lack thereof), more nuanced recognition was detected neurally via the N400, in that identifying meaning influenced how cognitive resources were allocated during recognition. The fact that we observed more effortful processing for novel nouns with a previously identified meaning regardless of behavioral recognition performance provides

evidence that the N400 revealed a component of the novel nouns' lexical representations that was not yet robust enough to influence recognition at an explicit level. Additionally, the MMN and N400 results of novel nouns with no identified meanings provided insights into what lexical information may or may not have been implicitly encoded. While novel nouns with no identified meanings that were incorrectly recognized appeared to have no implicit word form or semantic encoding, those that were correctly recognized still seemed to undergo word form and implicit semantic encoding. These implicit encoding findings highlight the value of using neural measures to explore underlying cognitive processes.

Yet, all these findings might be word-class specific. Nouns' semantic simplicity relative to verbs could mean that semantic processing is engaged to a different extent or in a different way during recognition than it is for verbs. Thus, we subsequently turned to verbs to examine the pattern of behavioral performance and neural engagement during recognition of a more semantically complex word class.

Experiment 2: Verbs

Method

Participants

Twenty-six participants completed the second experiment. One participant was excluded from analyses due to the demonstration of a handedness bias, as described above, one due to technical issues, and one due to excessive EEG artifacts. The final participant group included 23 right-handed, normal-hearing, monolingual English-speaking adults ($M = 20.87$, $SD = 1.14$, range = 19.05 to 23.05; all female). Exclusionary criteria were identical to that of Experiment 1. Also like Experiment 1, participants were recruited from undergraduate courses in Speech, Language, and Hearing Sciences at San Diego State University. In accordance with the Institutional Review Board of San Diego State University, all participants provided informed consent and received academic course credit for participation.

General Procedure

The general procedures, as well as the design of both the Encoding Task and Recognition Task, paralleled those reported for Experiment 1. Specific details regarding the stimuli and procedures for Experiment 2 are provided below.

Encoding Task

Stimuli. For Experiment 2, stimuli were developed to mirror Experiment 1 except that target words were verbs instead of nouns, thus requiring different sentences than in Experiment 1. Like Experiment 1, stimuli included 100 sets of

Table 2*Example Stimuli for the Encoding Task in Experiment 2*

Sentence Presentation	Supportive Context (target word: <i>cut</i>)	Unsupportive Context (no target word)
1	The thick paper was hard to <i>shap</i> .	In baseball you do not need to <i>darl</i> .
2	The chef needs a new knife to <i>shap</i> .	The movie took two hours to <i>darl</i> .
3	Sharp scissors make it easy to <i>shap</i> .	His lunch box was easy to <i>darl</i> .
Scoring Examples		
Meaning Identified	Cut, Slice, Bang	N/A
No Meaning Identified	No meaning	N/A

Note. Following the same construction as experiment 1, stimuli consisted of sentence triplets in which all three sentences ended with the same CVC novel word. In the supportive context, the novel word replaced the same early acquired verb target word in all three sentences of the triplet and the sentences increased in cloze probability across the triplet. In the unsupportive context, which served as a control condition, the novel word replaced a different early acquired verb in each of the triplet's three sentences, resulting in no target word, and the sentences were all low cloze probability. Participants' responses to stimuli from the supportive context were classified offline for meaning identification, disregarding response accuracy.

sentence triplets all containing a target word in the sentence-final position. In this study, the target word was an early acquired verb (Fenson et al., 2007; Hall et al., 1984). Sentences were all six to nine words in length and the words preceding the target word were either the infinitival *to* (e.g., *to run*) or a modal (e.g., *can*, *will*, *may*); thus, all verbs appeared in the non-finite form. Target words were replaced with the same novel words from Experiment 1 with minor changes to account for coarticulation effects (see Tables A2 and A3).

Just as in Experiment 1, for the Supportive Context, sentences within each triplet ended with the same target word and increased in cloze probability (Low: $M = 4.64$, $SD = 5.98$; Medium: $M = 39.42$, $SD = 10.34$; High: $M = 86.95$, $SD = 11.05$) and, for the Unsupportive Context, all sentences ended with a different target word and had low cloze probability ($M = 18.97$, $SD = 19.90$). For these stimuli, cloze probability was determined in the same way as for Experiment 1, but participants included 314 adults (238 of which were the same adults as those who normed the nouns; see Abel et al., 2015 for details). An adult female native

English speaker audio-recorded herself in a soundproof room speaking all sentences at a natural pace while using natural intonation to simulate optimal listening conditions (Length: Supportive Context: $M = 2,297.28$ ms, $SD = 355.25$ ms; Unsupportive Context: $M = 2,208.20$ ms, $SD = 331.79$ ms). Stimuli and scoring examples for Experiment 2 are provided in Table 2.

As in Experiment 1, we limited our focus to responses provided for the novel words from the Supportive Context and did not include responses for the novel words from the control condition (i.e., Unsupportive Context) in our analyses.

Recognition Task

The Recognition task stimuli, design, and procedure for Experiment 2 mirrored those used in Experiment 1. All novel words were produced by the same speaker as Experiment 2's Encoding Task and were recorded in the same way (Length: $M = 577.02$ ms, $SD = 121.36$ ms).

Behavioral Analysis

Experiment 2 used the same data (i.e., behavioral performance in the Recognition Task, quantified using A' for Meaning Identified and No Meaning Identified relative to New words) and statistical methods as Experiment 1.

EEG Acquisition and Pre-Processing and ERP Analysis

The EEG acquisition and pre-processing methods and ERP analysis for Experiment 2 mirrored those used in Experiment 1. Manual removal of components related to eye and head movement resulted in an average of 2.42 rejected components per participant ($SD = 1.04$). Data for electrodes with large impedances was interpolated, yielding 62 data channels for each participant (channels interpolated: $M = 2.7$, $SD = 1.89$). Following epoching -500 ms to 1000 ms after the presentation of the novel word, an average of 8.97 epochs were removed ($SD = 7.04$).

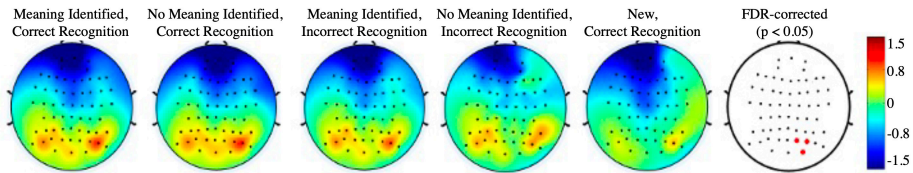
Results

Behavioral Results

During the Encoding Task, participants identified a meaning for 84.70% of the Supportive Context novel verbs ($SD = 0.36\%$). For the Recognition Task, the A' analysis showed that participants were significantly above chance at discriminating previously encountered novel verbs from new words ($M = 0.58$, $SD = 0.08$; $\beta = 0.08$, $SE = 0.02$, $t = 4.83$, $p < .001$). Discrimination from new words was also significantly above chance for novel verbs whose meanings *had* been identified during encoding ($M = 0.59$, $SD = 0.09$; $\beta = 0.09$, $SE = 0.02$, $t = 4.72$, $p < .001$), but not for verbs whose meanings had *not* been identified during encoding ($M = 0.54$, $SD = 0.22$; $\beta = 0.07$, $SE = 0.05$, $t = 1.51$, $p = .15$). Nevertheless, directly comparing A' values for verbs with versus without identified mean-

Figure 9

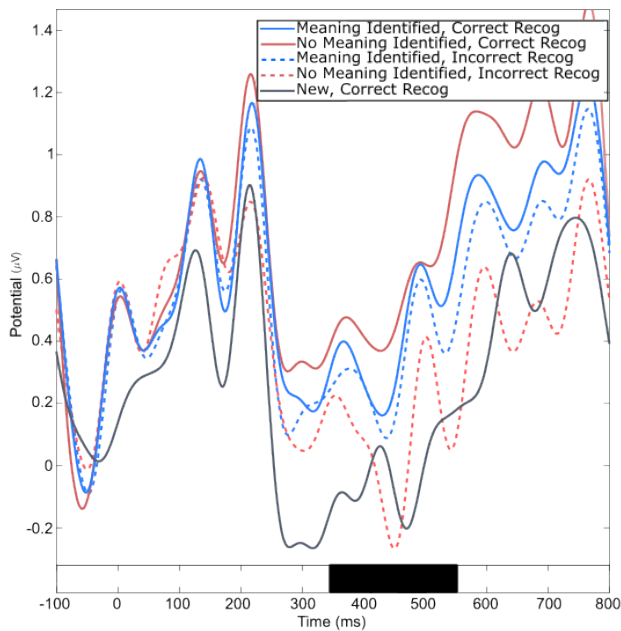
Scalp Maps of Verbs Representing Significant Differences between All Conditions from 350 to 550 ms after Target Word Onset



Note. Increases in ERP amplitude are represented in red, and decreases in ERP amplitude are represented in blue. Electrodes identified as significant by the cluster-based permutation test are highlighted in red on the far right scalp map (FDR-corrected p -values $< .05$).

Figure 10

ERP Waveforms of Verbs Representing Significant Differences between All Conditions from 350 to 550 ms after Target Onset



Note. Significant differences between 350 and 550 ms are highlighted by the black line along the x-axis. This ERP waveform is the average of all electrodes identified as significant in the cluster-based permutation test.

ings (each relative to new words) revealed no significant difference ($\beta = -0.05$, $SE = 0.05$, $t = -1.04$, $p = .30$). Recognition accuracy by word status is shown in Table A4 for descriptive purposes.

ERP Results

The cluster-based permutation analysis resulted in one significant cluster. There were no differences in the earlier MMN time window (30 to 170 ms). One cluster was identified in the N400 window between 350 and 550 ms over right centroparietal sites (see Figures 9 and 10; all significant corrected p -values $< .05$). Post-hoc analyses indicated this effect was driven by new novel words eliciting a significantly greater negativity than previously encountered novel verbs (i.e., Meaning Identified, Correct Recognition; Meaning Identified, Incorrect Recognition; No Meaning Identified, Correct Recognition), except for those where no meaning was identified and they were not correctly recognized (i.e., No Meaning Identified, Incorrect Recognition; see Figure A3). No other pairwise comparisons were significantly different.

Discussion

Similar to Experiment 1, in the Supportive Context condition of the Encoding Task, participants identified meanings for a large majority of novel verbs. Behaviorally, they also reliably discriminated previously encountered novel verbs from new words, demonstrating explicit recognition. However, counter to our prediction, behavioral recognition did not differ between previously encountered novel verbs with identified meanings and those without. As such, identifying a meaning during encoding did not facilitate later behavioral recognition of novel verbs.

Verbs' polysemous nature could have contributed to our finding that meaning identification did not facilitate behavioral recognition. The tendency for a single word form to be associated with several, often diverse, meanings only complicates lexical representation development (Foraker & Murphy, 2012; Fukink et al., 2001; Jenkins & Dixon, 1983). This experiment's design supported encoding only a single meaning for a word form; yet it is possible that participants encoded multiple meanings for a word form, and they merely reported the meaning with the most semantic support or the most memorable meaning. If that were the case, when participants encountered the word form at a later point, the competition among the several meanings might have hindered any facilitative effect encoding semantic information might have had on behavioral recognition. More research is needed to confirm this explanation. Beyond verb-specific features, the lack of facilitatory effect is also consistent with findings from noun stimuli (e.g., Abel et al., 2020; see also the findings from Experiment 1). This consistency across word classes holds implications for general lexical representation development, which are discussed in the General Discussion.

Examining the neural signals during the Recognition Task resulted in findings only related to the N400. Interestingly, our pattern of N400 results more closely aligned with a pattern based on implicit familiarity with the words rather than with explicit semantic encoding. Almost all novel verbs that had been previously encountered elicited a more attenuated N400 amplitude than new words. Like in Experiment 1, only novel verbs that participants had not identified a meaning for and incorrectly recognized did not follow this pattern. This attenuation for most previously encountered novel verbs suggests greater cognitive effort in attempting to access nonexistent lexical representations for new novel words compared to previously encountered novel verbs.

The general pattern of N400 results in the present study is in line with several previous studies' findings. In prior work similarly comparing neural responses to novel words with explicitly encoded meanings (i.e., old words) to new novel words immediately after the encoding phase (e.g., Bakker et al., 2015), new words elicited a more negative N400 than old words, generally consistent with our results. In addition, our findings align with those of Rugg, Curran, and others (e.g., Curran, 2000; Rugg et al., 1998; Rugg & Curran, 2007), who reported that a specific pattern of parietal neural activity occurring 300 to 500 ms post-stimulus onset to old and new stimuli is a correlate of implicit memory. While several different patterns of neural activity reflecting various aspects of semantic processing and memory have been found to occur during this time window (see, e.g., Rugg et al., 1998), each can be functionally and topographically disassociated. A defining feature of the implicit memory correlate is that the neural activity occurring 300 to 500 ms post-stimulus onset is elicited from widespread parietal electrodes, as partially reflected in our ERPs from this latency range. Moreover, as we found with the majority of our N400 results, the pattern of results associated with this index of implicit memory is that all old words, irrespective of other features (e.g., study or processing depth, recognition accuracy), elicit more positive-going waveforms than new words. Thus, our N400 results are broadly consistent with this established pattern of implicit recognition.

Together with the absence of any MMN effect, our findings serve as evidence that this implicit recognition was driven by semantic encoding. It is widely believed that any N400 effect, regardless of its topographical distribution, requires the encoding of semantic information (Kutas & Federmeier, 2011; Voss & Federmeier, 2011). Moreover, given the evidence that implicit semantic encoding can occur unconsciously (e.g., Brown et al., 2013; Durso & Shore, 1991; Frishkoff et al., 2010), we can interpret our findings as suggesting that participants implicitly encoded some semantic information for almost all novel verbs they encountered in the Encoding Task, even when they did not explicitly identify a meaning. Thus, given the alignment between the observed patterns of implicit and explicit recognition of previously encountered novel verbs versus new words, our N400 findings suggest implicit—rather than explicit—semantic encoding may have played a role in behavioral recognition of novel verbs.

In fact, it would seem that explicit meaning identification was only a determining factor for semantic encoding when behavioral recognition failed. In those cases, no semantic encoding appears to have occurred—explicitly or implicitly—as the N400 for those novel verbs tracked with that for new novel verbs. Again, we must be careful in interpreting these null effects. However, we may have found no differences between these two conditions because either lexical representations were not formed for unrecognized novel verbs with no identified meanings or, if some semantic information was encoded, the memory trace was too weak to functionally facilitate implicit recognition. Regardless, when our multiple behavioral measures indicated no semantic encoding, they were as informative as our neural measures. The neural signals did not reveal any additional evidence of semantic encoding beyond what was already evident behaviorally; both measures consistently pointed to a complete absence of semantic encoding. Overall, our N400 findings suggest that while implicit semantic encoding can occur even in the absence of explicit meaning identification, there are limits to this process.

An alternative interpretation of our findings is that the N400 effect reflects something beyond encoding exclusively semantic information. Our findings suggest the possibility that the N400 also reflects implicit encoding of syntactic information relevant to a word's meaning. Although the N400 is not typically a syntax-related ERP component, there is evidence that it is sensitive to syntactic violations (e.g., Hagoort, 2003). This sensitivity likely arises because syntactic information (e.g., argument structure) contributes to a word's meaning, especially in the case of verbs, and thus influences semantic processing (Hagoort, 2003). Perhaps, then, some degree of syntactic information was implicitly encoded for almost all novel verbs encountered in the Encoding Task, resulting in an N400 effect in the Recognition Task even when there was no explicit evidence meaning had been encoded. Future research should investigate this hypothesis.

However, verbs' unique semantic features (e.g., multiple meanings) and the aforementioned implications of the Encoding Task's focus on deducing a novel word's meaning (see Experiment 1: Nouns' Discussion) provide further support for the hypothesis of widespread semantic encoding and may explain the lack of word form encoding. The greater semantic complexity of verbs, coupled with the experimental task's design, may have led participants to unconsciously prioritize encoding any available semantic information over word form information when encountering novel verbs. Consequently, the memory traces for novel verbs' word forms were weak. This, combined with the phonological similarity of new and old word forms, may have prevented any word form from being more familiar than another at the neural level, leading to no MMN. A weak word-form memory trace might have also contributed to the finding that explicitly encoding semantic information did not facilitate behavioral recognition of novel verbs. Specifically, if the word-form memory trace is too weak to be activated when the word form is encountered later, the robustness of any linked semantic information has little

impact. This could lead to a lack of differences in neural and behavioral recognition between novel verbs with and without explicitly identified meanings. While the semantic information likely differs in robustness between these two types of lexical representations, a weak word form might obscure this distinction.

Taken together, it seems that semantic information has an impact on the recognition of novel verbs, albeit not in that explicit meaning identification supports later behavioral recognition as we predicted. According to the N400 findings, semantic encoding was not limited to novel verbs for which participants explicitly identified a meaning. Instead, meaning—but not form, per the MMN findings—was encoded to some extent for all novel verbs encountered in the Encoding Task except those with neither explicit semantic encoding nor behavioral recognition. This pattern of semantic encoding was in line with behavioral recognition of old versus new words: both distinguished previously encountered novel verbs from new words, suggesting behavioral recognition of novel verbs may reflect implicit semantic encoding. Thus, we found neural indicators of recognition for most previously encountered novel verbs based on the presence of memory traces for semantic information, paralleling aspects of explicit recognition.

General Discussion

Previous studies examining the impact of encoding word form and semantic information on recognition have found that, when semantic information must be deduced from an incidental context, recognition is supported, although the facilitation is only detectable at the neural level or after a delay (Abel et al., 2020; DuMay et al., 2004). Additionally, prior studies exploring word class differences in recognition have found nouns are generally recognized better than verbs (Earles & Kersten, 2017; Engelkamp & Zimmer, 1995; Kersten & Earles, 2004; Mohr et al., 1989; Reynolds & Flagg, 1976). Here, we bring together these two literatures to provide insight into the effect of encoding form and semantic information in incidental contexts on the recognition of novel nouns and verbs, demonstrating both similarities and differences in the recognition process across the two word classes.

Our first prediction revolved around behavioral recognition of novel nouns and verbs and the role of encoding semantic information. We found that identifying meaning during encoding did not facilitate better behavioral recognition of novel nouns or novel verbs, although previous exposure to the words did have an influence. Interestingly, we found this same pattern of performance across word classes. That is, behavioral discrimination between new words and each other word status (i.e., Meaning Identified, No Meaning Identified, and the aggregate of the two) did not differ between novel nouns and verbs (all $ps > .05$). Thus, it appears that even our unique approach of distinguishing between words with and without demonstrable evidence of form-meaning mapping was not sensitive enough to reveal the potentially facilitative effect of explicitly encoding

incidentally deduced semantic information on immediate behavioral recognition for either word class. However, this finding is consistent with previous studies using an incidental encoding paradigm that found no effect of explicitly encoding semantic information on behavioral recognition immediately following the encoding stage (Abel et al., 2020; Dumay et al., 2004).

Several possibilities could explain why explicitly encoding semantic information did not appear to support behavioral recognition. First, the similarity of novel word forms across the experiment (i.e., all CVC novel words) might have made it difficult to create sufficiently distinct lexical representations for each novel word. Even with the addition of semantic information to the lexical representation, this word form similarity could have introduced significant competition during lexical access and made distinguishing between words difficult. Additionally, as noted in the previous discussions, a weak word-form memory trace could have impacted participants' ability to adequately activate and access lexical representations. Word form is an essential component of lexical development, as a sufficiently robust word-form memory trace is instrumental to encoding and activating associated semantic information. As such, word form information plays an important role in the recognition process and could hinder activation and access despite adequate encoding of semantic information.

Another possibility is that the amount of semantic information provided might not have been sufficient to form a robust lexical representation. Previous studies have demonstrated that only three incidental exposures to a new word in a semantically rich context are necessary for the new word to elicit the same neural responses as a known word (Abel et al., 2018; Batterink & Neville, 2011; Mestres-Missé et al., 2007). However, our results, especially when considered with those of Abel et al. (2020) and Dumay et al. (2004), suggest that more exposures and/or a longer consolidation period might be needed to develop lexical representation memory traces robust enough to support behavioral recognition.

A final possibility is that the sheer number of new words encoded into memory in a relatively short period of time may have impacted behavioral accuracy. On average, participants successfully identified a meaning for 44 novel nouns or 42 novel verbs (out of 50) over the course of approximately one hour. This is a substantial number of new words to encode and recall with limited opportunity for consolidation. The large number of newly encoded words might have contributed to competition during the Recognition Task, regardless of the word form similarity or word-form memory trace strength. Moreover, with limited consolidation time, the robustness of the newly encoded lexical representations may have been compromised, even if the amount of semantic information encoded was sufficient.

Nevertheless, our finding of unfacilitated behavioral recognition following explicit semantic encoding is in line with our greater understanding of the incremental nature of the word learning process (e.g., Storkel, 2011). More specifically, it suggests that lexical representations of newly encountered words are not

robust enough for explicit encoding of incidentally provided semantic information to support behavioral recognition until later stages of lexical representation formation (e.g., after forming associations with existing lexical representations) substantially strengthen the memory trace. Thus, examining immediate recognition provides insight into only the early stages of lexical representation formation, and relying on explicit recognition is insufficient to capture subtle effects during these stages.

Given that models of word learning assume that all word classes undergo the same general process (e.g., Storkel, 2011), finding no difference in behavioral recognition accuracy for novel nouns versus novel verbs can be understood as a result of both word class's lexical representations being in the same early stage of development. The unexpected lack of word class differences also suggests that extracting semantic information from incidental contexts may "level the playing field" for developing lexical representations of new nouns and verbs. This is noteworthy given that the majority of words in one's lexicon are acquired via incidental (oral and/or written) contexts and that verbs are typically more difficult to acquire and retrieve (e.g., Bornstein et al., 2004; Gentner, 1981; Mätzig et al., 2009; Piccin & Waxman, 2007; Riches et al., 2005). If incidental contexts reduce word class differences, at least for learning a new word's meaning, then perhaps part of what underlies the developmental pattern of more easily learning and recognizing nouns over verbs is not challenges with abstracting and encoding semantic information for verbs, but with refining and integrating that information into verbs' lexical representations. More sensitive measures than behavioral ones are needed to investigate these potential nuances.

Including neural measures that are sensitive to implicit processing allows us to examine the earliest stages of lexical representation development that behavioral measures alone cannot capture. In addition, these measures can provide insight into the different mechanisms that drive word recognition. Across the two experiments, it became clear that implicit recognition of words, as indexed by the MMN and/or N400, occurred for both novel nouns and verbs, but the type of lexical information underlying that implicit recognition differed across word classes.

Although the MMN is traditionally examined in oddball paradigms, its links to word form familiarity make it a component of interest in the study of word learning and recognition. We had predicted that there would be no word class differences in the MMN given that word form is not inherently different across nouns and verbs and the word forms were intentionally manipulated to be the same whether they served as nouns or verbs across our experiments. Unexpectedly, our MMN results indicated that novel nouns produced different effects than novel verbs. There were no differences in the MMN across novel verbs whether they were old, new, recognized or not, or with or without an identified meaning. Conversely, the overarching MMN effect for novel nouns followed the predicted pattern, distinguishing between previously encountered and newly encountered

word forms, offering preliminary validation for our examination of the MMN in an incidental encoding paradigm rather than an oddball paradigm. The greater success with encoding word form information for novel nouns aligns with the evidence that nouns are recognized with greater ease and accuracy compared to verbs (Earles & Kersten, 2017; Engelkamp & Zimmer, 1995; Kersten & Earles, 2004; Mohr et al., 1989; Reynolds & Flagg, 1976). These findings with novel nouns suggest that word form familiarity may contribute to their behavioral recognition, consistent with the parallel distinction between previously encountered nouns and new words found in both our MMN and behavioral recognition results.

As with the MMN, analysis of the N400 led to valuable insights into the implicit processes underlying word recognition, specifically semantic encoding. We had predicted a pattern of greater N400 amplitude attenuation for words with an identified meaning compared to words without an identified meaning in both word classes but that the pattern would be more pronounced for novel verbs than novel nouns. We found that the pattern of N400 results did differ for verbs compared to nouns, although not in the way we had predicted. For both word classes, the N400 results indicated there was both implicit and explicit semantic encoding. In fact, the neural signals to all previously encountered words, across both word classes, showed some degree of semantic encoding, except for those lacking any behavioral evidence of it in both the Encoding Task and Recognition Task. However, semantic encoding influenced the processing of the words in each word class differently. Specifically, novel verbs with semantic encoding—whether implicit or explicit—were processed more easily than newly encountered words (i.e., words with no semantic encoding, primarily due a lack of opportunities for it). Contrastively, novel nouns with explicit semantic encoding required more effortful processing than those without, while novel nouns with solely implicit semantic encoding required less effortful processing than previously encountered novel nouns with no evidence of any semantic encoding. These findings underscore the complex role of semantic encoding in word recognition across word classes.

The implications of linked lexicosemantic associates, initially proposed to explain the noun findings in Experiment 1, may account for these semantic encoding patterns across word classes. If lexicosemantic associates are only linked when the memory trace for semantic information is sufficiently strong, and the semantic memory traces for verbs—whether the semantic information is implicitly or explicitly encoded—are weak, such linking may not have occurred. Consequently, like nouns with implicit semantic encoding, verbs with any form of semantic encoding would not be subject to the competition introduced by lexicosemantic linking, resulting in reduced rather than increased processing efforts. While this account provides a potential explanation for the observed processing differences, the extent to which lexicosemantic linking depends on memory trace strength requires empirical exploration. Thus, other explanations must also be considered.

One such alternative is that immediately following encoding, nouns and verbs differ in the alignment of their pre- and post-consolidation organization within the semantic network. According to the Complementary Learning Systems theory (Davis & Gaskell, 2009; Lindsay & Gaskell, 2010; McClelland et al., 1995), there are two functionally distinct but complementary neural systems for encoding and storing information in memory. Information is initially rapidly encoded and temporarily stored in the hippocampus, where representations are fragile and context dependent. Through offline consolidation processes (e.g., sleep), the information is gradually transferred to the neocortex, where it is integrated into existing memory systems (e.g., semantic memory) and stored long-term. Representations stored in the neocortex are stable and can influence other cognitive processes, such as spoken word recognition (Davis & Gaskell, 2009; Lindsay & Gaskell, 2010).

Applied to our findings, the N400 pattern may reflect processing costs specific to the immediate post-encoding stage (rather than a generalizable pattern of lexical acquisition difficulty), when representations are not yet incorporated into the semantic network. Nouns may require offline consolidation before being integrated into their cognitively advantageous hierarchical semantic organization, leading to more effortful processing during early retrieval. Verbs, in contrast, may immediately benefit from being anchored in relational or event-based contexts like those provided in our experiments, which naturally align with verbs' later matrix-like semantic organization. This immediate advantage may occur even if their long-term acquisition trajectory remains more challenging. In this way, our account is not incompatible with the broader literature showing verbs are harder to learn and process than nouns but instead highlights that lexical integration may differ across word classes, with distinct demands at immediate versus later stages of lexical development. However, even this explanation does not entirely account for our findings, as it does not coherently explain how nouns with implicit semantic encoding might elicit a pattern like that of verbs.

Another possibility for the differences in N400 effects across nouns and verbs arises from using an incidental encoding paradigm, in which participants had to use the linguistic context to infer meanings of words, to investigate learning across word classes. While the sentences comprising the sentence triplets were highly controlled within and across conditions (e.g., number of words in the sentences, location of the target word, the word directly preceding the target word), there are still inherent word class differences in the sentences that established the meanings of the target words. For instance, participants may have relied more heavily on nouns in the sentence to identify the meaning for the novel verb in the Verb condition and vice versa for the Noun condition.

Indeed, prior research has demonstrated that known nouns strongly inform the meaning of new verbs (e.g., Kasahara & Yanagisawa, 2024) and known verbs strongly inform the meaning of new nouns (e.g., Kasahara, 2015). One reason for this phenomenon is that each of these word classes constrains the range of possi-

ble meanings for a new word (e.g., Gillette et al., 1999; Kako & Trueswell, 2000; Kasahara, 2015; Kasahara & Yanagisawa, 2024). However, the nature of those possible meanings likely differs depending on whether the informative words are primarily nouns or verbs, given their distinct semantic organizations. It could be that the different ways known nouns and verbs guide the process of meaning identification for new words also differentially influence how semantic information is encoded for new nouns and verbs, thereby contributing to our unique pattern of findings. Further research is needed to investigate all these proposed explanations and determine the mechanisms underlying the contrastive N400 effects we observed after their replication.

Altogether, the observed ERP and behavioral effects provide evidence that, although immediate recognition of new words at the behavioral level is unaffected by explicitly encoding semantic information, distinct patterns emerge at the neural level. Across word classes, encoding semantic information influenced neural signals of recognition, while implicit recognition of word forms only occurred for novel nouns. Additionally, for nouns, neural indicators of word form encoding aligned with the old/new behavioral recognition distinction, whereas for verbs, this alignment was instead reflected in neural indicators of semantic encoding. Thus, word form and semantic information play distinctive roles in the implicit and explicit immediate recognition of novel nouns and verbs.

Strengths and Limitations

One of the key strengths of this study includes using a paradigm that is more representative of how individuals typically learn words than most studies exploring word recognition, especially those where a semantic meaning is explicitly provided along with a new word form (e.g., Balass et al., 2010; Takashima et al., 2014, 2017). Given that this is not how individuals learn most words (Nagy & Anderson, 1984; Nagy & Herman, 1987), our use of a more ecologically valid paradigm (albeit much more intense than an individual's typical lexicon-expanding experiences in adulthood unless they are immersively learning a foreign language) uniquely contributes to our understanding of lexical representation formation and access of newly formed lexical representations in real-life situations.

In addition, this study allowed us to isolate the effects of word class by using the same novel word forms paired with different word classes across conditions. We also controlled for the potential confounding variable of prior knowledge of a word form by using novel words as the new word forms for which participants were expected to identify a meaning. Other studies investigating word recognition have used highly infrequent real words (e.g., Balass et al., 2010; Frishkoff et al., 2008, 2009, 2010, 2011). In these designs, it is possible that participants already had lexical representations for the test words, even if the encoded lexical information was limited. By using novel words, we prevented any prior level of familiarity or encoded lexical information from influencing our outcomes. Also, our samples of only monolingual participants allowed us to control for any ef-

fects of bilingualism, although that is an area ripe for further investigation.

Despite these strengths, the study also had some limitations, creating avenues for future research. Although the tasks were already time-consuming, greater control could have been achieved if, instead of the between-subject design, each participant had completed both experiments and, thus, contributed data for both word classes. Also, while our participant inclusion criteria allowed strict control of several possible confounding variables, the use of only neurotypical, monolingual, college-educated undergraduate students with typical language development is not a representative sample of the larger population and limits the generalizability of this study's findings. Future research should explore these effects in more diverse populations, including individuals with and without language difficulties.

This study also focused on explicit recognition of a word's phonological form rather than its meaning. Thus, future work should consider using a paradigm that is equipped to examine the nature of the semantic information that can be accessed so as to better understand the impacts of encoding semantic information on word recognition. A more detailed investigation into the effects of syntactic elements of the context in which a new word is encountered on word recognition could also provide additional insights. For example, in this study, both nouns and verbs were preceded by one of two different modifiers (i.e., a determiner or possessive pronoun for nouns, and infinitival *to* or a modal auxiliary for verbs). However, we did not explore how performance might have varied by these syntactic differences. This level of fine-grained analysis was not directly relevant to our research question, but future studies could explore these comparisons to further refine our understanding of how word class and syntax influence recognition.

Additionally, in the Recognition Task there were twice as many new words as there were previously encountered words from the Supportive Context and, further, the words from the Supportive Context were classified based on participants' responses (i.e., whether they identified a meaning for the novel word). This led to a different number of trials per condition in both of the experiments (see Table A5). Visual inspection of the EEG data showed no clear impacts of these different numbers of trials. However, the relatively smaller number of trials in the Meaning Identified and No Meaning Identified conditions may have affected signal-to-noise ratios and subsequent findings. Lastly, we aligned ERPs to the onset of the novel words, as is standard in N400 studies due to immediate initiation of semantic processing upon encountering a word and to avoid contamination from movement-based electrical activity generated when responding with button presses. This approach is also consistent with the studies to which we compared our results, which allowed for valid comparisons. However, aligning ERPs to the offset of the novel words instead could be a valuable direction for future research, providing insight into the neural processes after the novel word has been heard in full and semantic processing is already underway.

Conclusion

In conclusion, this study provides insights into the impact of encoding form and semantic information in incidental contexts and word class on explicit and implicit recognition of new words. We found that explicitly encoding incidentally provided semantic information did not observably facilitate the immediate behavioral recognition of either novel nouns or verbs, with both word classes unexpectedly showing equivalent behavioral performance. However, neural measures indexing processes underlying recognition, specifically word form familiarity via the MMN and semantic processing via the N400, revealed distinct patterns of neural engagement across word classes. At the neural level, there was pronounced word form encoding for novel nouns, which tracked with and, thus, may have guided behavioral recognition of old from new words. In addition, novel nouns with explicitly encoded meanings required more effortful processing than those without. However, among novel nouns with no explicitly encoded meanings, those that were later correctly recognized required less effortful processing than those that were incorrectly recognized, suggesting implicit semantic encoding for the former. For novel verbs, there were no neural indications of word form encoding but indications of broad semantic encoding. That is, meanings were at least implicitly encoded for all previously encountered novel verbs except for those with no identified meanings that were incorrectly recognized later, tracking with, and perhaps underlying, old/new behavioral recognition with novel verbs. Taken together, these findings suggest that while explicitly encoding incidentally obtained semantic information may not improve immediate behavioral recognition of newly learned words, implicitly encoded information may. Regardless of its role in explicit recognition, encoded word form and/or semantic information is reliably reflected in neural indicators of implicit recognition, with the relative contributions of form and meaning varying across word class. Overall, these results underscore the nuanced and incremental nature of lexical representation formation, especially with regard to encoding form and semantic information, and how that process differs across nouns and verbs.

Authorship Details

Ashlie Hope Pankonin: research concept and design, collection and/or assembly of data, data analysis and interpretation, writing the article, critical revision of the article, final approval of the article.

Julie M. Schneider: data analysis and interpretation, writing the article, critical revision of the article, final approval of the article.

Alyson D. Abel: research concept and design, collection and/or assembly of data, data analysis and interpretation, writing the article, critical revision of the article, final approval of the article.

Conflict of Interest Disclosure

The authors reports no conflicts of interest.

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Research Ethics Statement

All participants, who were of the age of majority, provided informed consent. The study was approved by the Institutional Review Board of San Diego State University (IRB#: 1910097), and participant rights and well-being were protected throughout.

Data Availability Statement

All of our materials, anonymized data, and analysis code are available in a freely accessible online repository: osf.io/m7u6c.

References

- Abel, A. D., Maguire, M. J., Naqvi, F. M., & Kim, A. Y. (2015). Lexical retrieval of nouns and verbs in a sentence completion task. *Journal of Psycholinguistic Research*, 44(5), 545–553. <https://doi.org/10.1007/s10936-014-9304-8>
- Abel, A. D., Schneider, J., & Maguire, M. J. (2018). N400 response indexes word learning from linguistic context in children. *Language Learning and Development*, 14(1), 61–71. <https://doi.org/10.1080/15475441.2017.1362347>
- Abel, A. D., Sharp, B. J., & Konja, C. (2020). Investigating implicit and explicit word learning in school-age children using a combined behavioral-event related potential (ERP) approach. *Developmental Neuropsychology*, 45(1), 27–38. <https://doi.org/10.1080/87565641.2019.1709465>
- Aleksandrov, A. A., Memetova, K. S., Stankevich, L. N., Knyazeva, V. M., & Shtyrov, Y. (2020). Referent's lexical frequency predicts mismatch negativity responses to new words following semantic training. *Journal of Psycholinguistic Research*, 49(2), 187–198. <https://doi.org/10.1007/s10936-019-09678-3>
- Bakker, I., Takashima, A., Van Hell, J. G., Janzen, G., & McQueen, J. M. (2015). Tracking lexical consolidation with ERPs: Lexical and semantic-priming effects on N400 and LPC responses to newly-learned words. *Neuropsychologia*, 79, 33–41. <https://doi.org/10.1016/j.neuropsychologia.2015.10.020>
- Balass, M., Nelson, J. R., & Perfetti, C. A. (2010). Word learning: An ERP investigation of word experience effects on recognition and word processing. *Contemporary Educational Psychology*, 35(2), 126–140. <https://doi.org/10.1016/j.cedpsych.2010.04.001>
- Barr, D. J., Levy, R., Scheepers, C., & Tily, H. J. (2013). Random effects structure for confirmatory hypothesis testing: Keep it maximal. *Journal of Memory and Language*, 68(3), 255–278. <https://doi.org/10.1016/j.jml.2012.11.001>
- Bates, D., Kliegl, R., Vasishth, S., & Baayen, H. (2018). *Parsimonious mixed models*. ArXiv. <https://doi.org/10.48550/arXiv.1506.04967>
- Bates, D., Maechler, M., Bolker, B., & Walker, S. (2015). Fitting linear mixed-effects models using “lme4.” *Journal of Statistical Software*, 67(1), 1–48. <https://doi.org/10.18637/jss.v067.i01>
- Batterink, L., & Neville, H. (2011). Implicit and explicit mechanisms of word learning in a narrative context: An event-related potential study. *Journal of Cognitive Neuroscience*, 23(11), 3181–3196. https://doi.org/10.1162/jocn_a_00013
- Bolger, D. J., Balass, M., Landen, E., & Perfetti, C. A. (2008). Context variation and definitions in learning the meanings of words: An instance-based learning approach. *Discourse Processes*, 45(2), 122–159. <https://doi.org/10.1080/01638530701792826>
- Bornstein, M. H., Cote, L. R., Maital, S., Painter, K., Park, S.-Y., Pascual, L., Pêcheux, M.-G., Ruel, J., Venuti, P., & Vyt, A. (2004). Cross-linguistic anal-

- ysis of vocabulary in young children: Spanish, Dutch, French, Hebrew, Italian, Korean, and American English. *Child Development*, 75(4), 1115–1139. <https://doi.org/10.1111/j.1467-8624.2004.00729.x>
- Brauer, M., & Curtin, J. J. (2018). Linear mixed-effects models and the analysis of nonindependent data: A unified framework to analyze categorical and continuous independent variables that vary within-subjects and/or within-items. *Psychological Methods*, 23, 389–411. <https://doi.org/10.1037/met0000159>
- Brown, A. S., Burrows, C. N., & Croft Caderao, K. (2013). Partial word knowledge in the absence of recall. *Memory & Cognition*, 41(7), 967–977. <https://doi.org/10.3758/s13421-013-0321-x>
- Colombo, L., & Burani, C. (2002). The influence of age of acquisition, root frequency, and context availability in processing nouns and verbs. *Brain and Language*, 81(1), 398–411. <https://doi.org/10.1006/brln.2001.2533>
- Curran, T. (2000). Brain potentials of recollection and familiarity. *Memory & Cognition*, 28(6), 923–938. <https://doi.org/10.3758/BF03209340>
- Davis, M. H., & Gaskell, M. G. (2009). A complementary systems account of word learning: Neural and behavioural evidence. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 364(1536), 3773–3800. <https://doi.org/10.1098/rstb.2009.0111>
- Delorme, A., & Makeig, S. (2004). EEGLAB: An open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. *Journal of Neuroscience Methods*, 134(1), 9–21. <https://doi.org/10.1016/j.jneumeth.2003.10.009>
- Delorme, A., Makeig, S., & Sejnowski, T. (2001). Automatic artifact rejection for EEG data using high-order statistics and independent component analysis. *Proceedings of the Third International ICA Conference*, 9–12.
- Dollaghan, C., & Campbell, T. F. (1998). Nonword repetition and child language impairment. *Journal of Speech, Language, and Hearing Research*, 41(5), 1136–1146. <https://doi.org/10.1044/jslhr.4105.1136>
- Druks, J. (2002). Verbs and nouns—A review of the literature. *Journal of Neurolinguistics*, 15(3), 289–315. [https://doi.org/10.1016/S0911-6044\(01\)00029-X](https://doi.org/10.1016/S0911-6044(01)00029-X)
- Dumay, N., & Gaskell, M. G. (2007). Sleep-associated changes in the mental representation of spoken words. *Psychological Science*, 18(1), 35–39. <https://doi.org/10.1111/j.1467-9280.2007.01845.x>
- Dumay, N., Gaskell, M. G., & Feng, X. (2004). A day in the life of a spoken word. *Proceedings of the Annual Meeting of the Cognitive Science Society*, 26, 339–344. <https://escholarship.org/uc/item/0cq32170>
- Durso, F., & Shore, W. (1991). Partial knowledge of word meanings. *Journal of Experimental Psychology: General*, 120, 190–202. <https://doi.org/10.1037/0096-3445.120.2.190>
- Earles, J. L., & Kersten, A. W. (2017). Why are verbs so hard to remember? Effects of semantic context on memory for verbs and nouns. *Cognitive Science*, 41, 780–807. <https://doi.org/10.1111/cogs.12374>

- Engelkamp, J., & Zimmer, H. D. (1995). Similarity of movement in recognition of self-performed tasks and of verbal tasks. *British Journal of Psychology*, 86(2), 241–252. <https://doi.org/10.1111/j.2044-8295.1995.tb02559.x>
- Ernst, M. D. (2004). Permutation methods: A basis for exact inference. *Statistical Science*, 19(4), 676–685. <https://doi.org/10.1214/088342304000000396>
- Federmeier, K. D., & Bates, E. (1997). Contexts that pack a punch: Lexical class priming of picture naming. *Center for Research in Language Newsletter*, 11(2), 1–13. <https://crl.ucsd.edu/newsletter/11-2/11-2.pdf>
- Federmeier, K. D., & Kutas, M. (1999). A rose by any other name: Long-term memory structure and sentence processing. *Journal of Memory and Language*, 41(4), 469–495. <https://doi.org/10.1006/jmla.1999.2660>
- Federmeier, K. D., Segal, J. B., Lombrozo, T., & Kutas, M. (2000). Brain responses to nouns, verbs and class-ambiguous words in context. *Brain*, 123(12), 2552–2566. <https://doi.org/10.1093/brain/123.12.2552>
- Fenson, L., Marchman, V. A., Thal, D., Dale, P. S., Reznick, S. J., & Bates, E. (2007). *MacArthur-Bates communicative development inventories: User's guide and technical manual* (2nd ed.). Brookes.
- Foraker, S., & Murphy, G. L. (2012). Polysemy in sentence comprehension: Effects of meaning dominance. *Journal of Memory and Language*, 67(4), 407–425. <https://doi.org/10.1016/j.jml.2012.07.010>
- Frishkoff, G. A., Collins-Thompson, K., Perfetti, C. A., & Callan, J. (2008). Measuring incremental changes in word knowledge: Experimental validation and implications for learning and assessment. *Behavior Research Methods*, 40(4), 907–925. <https://doi.org/10.3758/BRM.40.4.907>
- Frishkoff, G. A., Perfetti, C. A., & Collins-Thompson, K. (2010). Lexical quality in the brain: ERP evidence for robust word learning from context. *Developmental Neuropsychology*, 35(4), 376–403. <https://doi.org/10.1080/87565641.2010.480915>
- Frishkoff, G. A., Perfetti, C. A., & Collins-Thompson, K. (2011). Predicting robust vocabulary growth from measures of incremental learning. *Scientific Studies of Reading*, 15(1), 71–91. <https://doi.org/10.1080/10888438.2011.539076>
- Frishkoff, G. A., Perfetti, C. A., & Westbury, C. (2009). ERP measures of partial semantic knowledge: Left temporal indices of skill differences and lexical quality. *Biological Psychology*, 80(1), 130–147. <https://doi.org/10.1016/j.biopsycho.2008.04.017>
- Fukking, R. G. (2005). Deriving word meaning from written context: A process analysis. *Learning and Instruction*, 15(1), 23–43. <https://doi.org/10.1016/j.learninstruc.2004.12.002>
- Fukking, R. G., Blok, H., & Glopper, K. de. (2001). Deriving word meaning from written context: A multicomponential skill. *Language Learning*, 51(3), 477–496. <https://doi.org/10.1111/0023-8333.00162>
- Garrido, M. I., Kilner, J. M., Stephan, K. E., & Friston, K. J. (2009). The mis-

- match negativity: A review of underlying mechanisms. *Clinical Neurophysiology*, 120(3), 453–463. <https://doi.org/10.1016/j.clinph.2008.11.029>
- Gaskell, M. G., & Dumay, N. (2003). Lexical competition and the acquisition of novel words. *Cognition*, 89(2), 105–132. [https://doi.org/10.1016/S0010-0277\(03\)00070-2](https://doi.org/10.1016/S0010-0277(03)00070-2)
- Gathercole, S. E. (2006). Nonword repetition and word learning: The nature of the relationship. *Applied Psycholinguistics*, 27(4), 513–543. <https://doi.org/10.1017/S0142716406060383>
- Gentner, D. (1981). Some interesting differences between nouns and verbs. *Cognition and Brain Theory*, 4, 161–178. <https://groups.psych.northwestern.edu/gentner/papers/Gentner81c.pdf>
- Gentner, D., & Boroditsky, L. (2001). Individuation, relativity, and early word learning. In M. Bowerman & S. Levinson (Eds.), *Language acquisition and conceptual development* (pp. 215–256). Cambridge University Press.
- Gentner, D., & France, I. M. (1988). The verb mutability effect: Studies of the combinatorial semantics of nouns and verbs. In S. L. Small, G. W. Cottrell, & M. K. Tanenhaus (Eds.), *Lexical ambiguity resolution* (pp. 343–382). Morgan Kaufmann. <https://doi.org/10.1016/B978-0-08-051013-2.50018-5>
- Gillette, J., Gleitman, H., Gleitman, L., & Lederer, A. (1999). Human simulations of vocabulary learning. *Cognition*, 73(2), 135–176. [https://doi.org/10.1016/S0010-0277\(99\)00036-0](https://doi.org/10.1016/S0010-0277(99)00036-0)
- Gomes, H., Ritter, W., Tarter, V. C., Vaughan, H. G., & Rosen, J. J. (1997). Lexical processing of visually and auditorily presented nouns and verbs: Evidence from reaction time and N400 priming data. *Cognitive Brain Research*, 6(2), 121–134. [https://doi.org/10.1016/S0926-6410\(97\)00023-2](https://doi.org/10.1016/S0926-6410(97)00023-2)
- Goulden, R., Nation, P., & Read, J. (1990). How large can a receptive vocabulary be? *Applied Linguistics*, 11(4), 341–363. <https://doi.org/10.1093/applin/11.4.341>
- Groppe, D. M., Urbach, T. P., & Kutas, M. (2011a). Mass univariate analysis of event-related brain potentials/fields I: A critical tutorial review. *Psychophysiology*, 48(12), 1711–1725. <https://doi.org/10.1111/j.1469-8986.2011.01273.x>
- Groppe, D. M., Urbach, T. P., & Kutas, M. (2011b). Mass univariate analysis of event-related brain potentials/fields II: Simulation studies. *Psychophysiology*, 48(12), 1726–1737. <https://doi.org/10.1111/j.1469-8986.2011.01272.x>
- Hagoort, P. (2003). Interplay between syntax and semantics during sentence comprehension: ERP effects of combining syntactic and semantic violations. *Journal of Cognitive Neuroscience*, 15(6), 883–899. <https://doi.org/10.1162/089892903322370807>
- Hall, W. S., Nagy, W. E., & Linn, R. L. (1984). *Spoken words, effects of situation and social group on oral word usage and frequency*. Lawrence Erlbaum Associates.
- Hasting, A. S., Winkler, I., & Kotz, S. A. (2008). Early differential processing of verbs and nouns in the human brain as indexed by event-related brain po-

- tentials. *European Journal of Neuroscience*, 27(6), 1561–1565. <https://doi.org/10.1111/j.1460-9568.2008.06103.x>
- Holcomb, P. J., & Neville, H. J. (1991). Natural speech processing: An analysis using event-related brain potentials. *Psychobiology*, 19(4), 286–300. <https://doi.org/10.3758/BF03332082>
- Hu, A., Gu, F., Wong, L. L. N., Tong, X., & Zhang, X. (2020). Visual mismatch negativity elicited by semantic violations in visual words. *Brain Research*, 1746, 147010. <https://doi.org/10.1016/j.brainres.2020.147010>
- Huttenlocher, J., & Lui, F. (1979). The semantic organization of some simple nouns and verbs. *Journal of Verbal Learning and Verbal Behavior*, 18(2), 141–162. [https://doi.org/10.1016/S0022-5371\(79\)90091-4](https://doi.org/10.1016/S0022-5371(79)90091-4)
- Jacobsen, T., Bäß, P., Roye, A., Winkler, I., Schröger, E., & Horváth, J. (2021). Word class and word frequency in the MMN looking glass. *Brain and Language*, 218, 104964. <https://doi.org/10.1016/j.bandl.2021.104964>
- Jacobsen, T., Schröger, E., Winkler, I., & Horváth, J. (2005). Familiarity affects the processing of task-irrelevant auditory deviance. *Journal of Cognitive Neuroscience*, 17(11), 1704–1713. <https://doi.org/10.1162/089892905774589262>
- Jenkins, J. R., & Dixon, R. (1983). Vocabulary learning. *Contemporary Educational Psychology*, 8(3), 237–260. [https://doi.org/10.1016/0361-476X\(83\)90016-4](https://doi.org/10.1016/0361-476X(83)90016-4)
- Kako, E., & Trueswell, J. C. (2000). Verb meanings, object affordances, and the incremental restrictions of reference. *Proceedings of the Annual Meeting of the Cognitive Science Society*, 22. <https://escholarship.org/uc/item/3x16656j>
- Kasahara, K. (2015). Which cues, adjectives or verbs, provide most assistance for remembering new nouns? *ARELE: Annual Review of English Language Education in Japan*, 26, 317–332. https://doi.org/10.20581/arele.26.0_317
- Kasahara, K., & Yanagisawa, A. (2024). Learning new verbs with known cue words: The relative effects of noun and adverb cues. *Language Teaching Research*, 28(1), 138–155. <https://doi.org/10.1177/13621688211001613>
- Kauschke, C., & von Frankenberg, J. (2008). The differential influence of lexical parameters on naming latencies in German. A study on noun and verb picture naming. *Journal of Psycholinguistic Research*, 37(4), 243–257. <https://doi.org/10.1007/s10936-007-9068-5>
- Kersten, A. W. (1998). A division of labor between nouns and verbs in the representation of motion. *Journal of Experimental Psychology: General*, 127(1), 34–54. <https://doi.org/10.1037/0096-3445.127.1.34>
- Kersten, A. W. (2003). Verbs and nouns convey different types of motion in event descriptions. *Linguistics*, 41(5), 917–945. <https://doi.org/10.1515/ling.2003.030>
- Kersten, A. W., & Earles, J. L. (2004). Semantic context influences memory for verbs more than memory for nouns. *Memory & Cognition*, 32(2), 198–211. <https://doi.org/10.3758/BF03196852>
- Khader, P., Scherag, A., Streb, J., & Rösler, F. (2003). Differences between noun

- and verb processing in a minimal phrase context: A semantic priming study using event-related brain potentials. *Cognitive Brain Research*, 17(2), 293–313. [https://doi.org/10.1016/S0926-6410\(03\)00130-7](https://doi.org/10.1016/S0926-6410(03)00130-7)
- Kiefer, M. (2002). The N400 is modulated by unconsciously perceived masked words: Further evidence for an automatic spreading activation account of N400 priming effects. *Cognitive Brain Research*, 13(1), 27–39. [https://doi.org/10.1016/S0926-6410\(01\)00085-4](https://doi.org/10.1016/S0926-6410(01)00085-4)
- Kintsch, W. (2001). Predication. *Cognitive Science*, 25(2), 173–202. https://doi.org/10.1207/s15516709cog2502_1
- Koriat, A., Levy-Sadot, R., Edry, E., & De Marcas, S. (2003). What do we know about what we cannot remember? Accessing the semantic attributes of words that cannot be recalled. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 29(6), 1095–1105. <https://doi.org/10.1037/0278-7393.29.6.1095>
- Kutas, M., & Federmeier, K. D. (2011). Thirty years and counting: Finding meaning in the N400 component of the event-related brain potential (ERP). *Annual Review of Psychology*, 62(1), 621–647. <https://doi.org/10.1146/annurev.psych.093008.131123>
- Kutas, M., & Hillyard, S. A. (1980). Reading senseless sentences: Brain potentials reflect semantic incongruity. *Science*, 207(4427), 203–205. <https://doi.org/10.1126/science.7350657>
- Laszlo, S., & Federmeier, K. D. (2011). The N400 as a snapshot of interactive processing: Evidence from regression analyses of orthographic neighbor and lexical associate effects. *Psychophysiology*, 48(2), 176–186. <https://doi.org/10.1111/j.1469-8986.2010.01058.x>
- Leach, L., & Samuel, A. (2007). Lexical configuration and lexical engagement: When adults learn new words. *Cognitive Psychology*, 55(4), 306–353. <https://doi.org/10.1016/j.cogpsych.2007.01.001>
- Lee, C., & Federmeier, K. D. (2006). To mind the mind: An event-related potential study of word class and semantic ambiguity. *Brain Research*, 1081(1), 191–202. <https://doi.org/10.1016/j.brainres.2006.01.058>
- Levin, B. (1993). *English verb classes and alternations: A preliminary investigation*. University of Chicago Press.
- Lindsay, S., & Gaskell, M. G. (2010). A complementary systems account of word learning in L1 and L2. *Language Learning*, 60(s2), 45–63. <https://doi.org/10.1111/j.1467-9922.2010.00600.x>
- Lopez-Calderon, J., & Luck, S. J. (2014). ERPLAB: An open-source toolbox for the analysis of event-related potentials. *Frontiers in Human Neuroscience*, 8. <https://www.frontiersin.org/article/10.3389/fnhum.2014.00213>
- Maris, E., & Oostenveld, R. (2007). Nonparametric statistical testing of EEG- and MEG-data. *Journal of Neuroscience Methods*, 164(1), 177–190. <https://doi.org/10.1016/j.jneumeth.2007.03.024>
- Mätzig, S., Druks, J., Masterson, J., & Vigliocco, G. (2009). Noun and verb dif-

- ferences in picture naming: Past studies and new evidence. *Cortex*, 45(6), 738–758. <https://doi.org/10.1016/j.cortex.2008.10.003>
- McClelland, J. L., McNaughton, B. L., & O'Reilly, R. C. (1995). Why there are complementary learning systems in the hippocampus and neocortex: Insights from the successes and failures of connectionist models of learning and memory. *Psychological Review*, 102(3), 419–457. <https://doi.org/10.1037/0033-295X.102.3.419>
- Mestres-Missé, A., Rodriguez-Fornells, A., & Munte, T. F. (2007). Watching the brain during meaning acquisition. *Cerebral Cortex*, 17(8), 1858–1866. <https://doi.org/10.1093/cercor/bhl094>
- Misra, M., & Holcomb, P. J. (2003). Event-related potential indices of masked repetition priming. *Psychophysiology*, 40(1), 115–130. <https://doi.org/10.1111/1469-8986.00012>
- Mohr, G., Engelkamp, J., & Zimmer, H. D. (1989). Recall and recognition of self-performed acts. *Psychological Research*, 51(4), 181–187. <https://doi.org/10.1007/BF00309146>
- Momsen, J. P., & Abel, A. D. (2021). Neural oscillations reflect meaning identification for novel words in context. *Neurobiology of Language*, 3(1), 132–148. https://doi.org/10.1162/nol_a_00052
- Näätänen, R., Lehtokoski, A., Lennes, M., Cheour, M., Huottilainen, M., Iivonen, A., Vainio, M., Alku, P., Ilmoniemi, R. J., Luuk, A., Allik, J., Sinkkonen, J., & Alho, K. (1997). Language-specific phoneme representations revealed by electric and magnetic brain responses. *Nature*, 385(6615), Article 6615. <https://doi.org/10.1038/385432a0>
- Nagy, W. E., & Anderson, R. C. (1984). How many words are there in printed school English? *Reading Research Quarterly*, 19(3), 304–330. <https://doi.org/10.2307/747823>
- Nagy, W. E., & Herman, P. A. (1987). Breadth and depth of vocabulary knowledge: Implications for acquisition and instruction. In M. G. McKeown & M. E. Curtis (Eds.), *The nature of vocabulary acquisition* (pp. 19–36). Lawrence Erlbaum Associates, Inc.
- Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh inventory. *Neuropsychologia*, 9(1), 97–113. [https://doi.org/10.1016/0028-3932\(71\)90067-4](https://doi.org/10.1016/0028-3932(71)90067-4)
- Oostenveld, R., Fries, P., Maris, E., & Schoffelen, J.-M. (2011). FieldTrip: Open source software for advanced analysis of MEG, EEG, and invasive electrophysiological data. *Computational Intelligence and Neuroscience*, 2011, 1–9. <https://doi.org/10.1155/2011/156869>
- Pettigrew, C., Murdoch, B., Kei, J., Ponton, C., Alku, P., & Chenery, H. (2005). The mismatch negativity (MMN) response to complex tones and spoken words in individuals with aphasia. *Aphasiology*, 19(2), 131–163. <https://doi.org/10.1080/02687030444000642>
- Piccin, T. B., & Waxman, S. R. (2007). Why nouns trump verbs in word learn-

- ing: New evidence from children and adults in the Human Simulation Paradigm. *Language Learning and Development*, 3(4), 295–323. <https://doi.org/10.1080/15475440701377535>
- Pulvermüller, F., Kujala, T., Shtyrov, Y., Simola, J., Tiitinen, H., Alku, P., Alho, K., Martinkauppi, S., Ilmoniemi, R. J., & Näätänen, R. (2001). Memory traces for words as revealed by the mismatch negativity. *NeuroImage*, 14(3), 607–616. <https://doi.org/10.1006/nimg.2001.0864>
- Reynolds, A. G., & Flagg, P. W. (1976). Recognition memory for elements of sentences. *Memory & Cognition*, 4(4), 422–432. <https://doi.org/10.3758/BF03213199>
- Riches, N. G., Tomasello, M., & Conti-Ramsden, G. M. (2005). Verb learning in children with SLI. *Journal of Speech, Language, and Hearing Research*, 48(6), 1397–1411. [https://doi.org/10.1044/1092-4388\(2005/097\)](https://doi.org/10.1044/1092-4388(2005/097))
- Rösler, F., Streb, J., & Haan, H. (2001). Event-related brain potentials evoked by verbs and nouns in a primed lexical decision task. *Psychophysiology*, 38(4), 694–703. <https://doi.org/10.1111/1469-8986.3840694>
- Rugg, M. D., & Curran, T. (2007). Event-related potentials and recognition memory. *Trends in Cognitive Sciences*, 11(6), 251–257. <https://doi.org/10.1016/j.tics.2007.04.004>
- Rugg, M. D., Mark, R. E., Walla, P., Schloerscheidt, A. M., Birch, C. S., & Allan, K. (1998). Dissociation of the neural correlates of implicit and explicit memory. *Nature*, 392(6676), Article 6676. <https://doi.org/10.1038/33396>
- Sereno, S. C., Brewer, C. C., & O'Donnell, P. J. (2003). Context effects in word recognition: Evidence for early interactive processing. *Psychological Science*, 14(4), 328–333. <https://doi.org/10.1111/1467-9280.14471>
- Shore, W. J., & Kempe, V. (1999). The role of sentence context in accessing partial knowledge of word meanings. *Journal of Psycholinguistic Research*, 28(2), 145–163. <https://doi.org/10.1023/A:1023258224980>
- Shtyrov, Y., Nikulin, V. V., & Pulvermüller, F. (2010). Rapid cortical plasticity underlying novel word learning. *Journal of Neuroscience*, 30(50), 16864–16867. <https://doi.org/10.1523/JNEUROSCI.1376-10.2010>
- Shtyrov, Y., & Pulvermüller, F. (2002). Neurophysiological evidence of memory traces for words in the human brain. *NeuroReport*, 13(4), 521. <https://doi.org/10.1097/00001756-200203250-00033>
- Stanislaw, H., & Todorov, N. (1999). Calculation of signal detection theory measures. *Behavior Research Methods, Instruments, & Computers*, 31(1), 137–149. <https://doi.org/10.3758/BF03207704>
- Storkel, H. L. (2011). Differentiating word learning processes may yield new insights – A commentary on Stoel-Gammon's 'Relationships between lexical and phonological development in young children'. *Journal of Child Language*, 38(1), 51–55. <https://doi.org/10.1017/S0305000910000486>
- Storkel, H. L. (2013). A corpus of consonant–vowel–consonant real words and nonwords: Comparison of phonotactic probability, neighborhood density,

- and consonant age of acquisition. *Behavior Research Methods*, 45(4), 1159–1167. <https://doi.org/10.3758/s13428-012-0309-7>
- Szekely, A., D'Amico, S., Devescovi, A., Federmeier, K., Herron, D., Iyer, G., Jacobsen, T., Arévalo, A. L., Vargha, A., & Bates, E. (2005). Timed action and object naming. *Cortex*, 41(1), 7–25. [https://doi.org/10.1016/S0010-9452\(08\)70174-6](https://doi.org/10.1016/S0010-9452(08)70174-6)
- Takashima, A., Bakker, I., van Hell, J. G., Janzen, G., & McQueen, J. M. (2014). Richness of information about novel words influences how episodic and semantic memory networks interact during lexicalization. *NeuroImage*, 84, 265–278. <https://doi.org/10.1016/j.neuroimage.2013.08.023>
- Takashima, A., Bakker, I., van Hell, J. G., Janzen, G., & McQueen, J. M. (2017). Interaction between episodic and semantic memory networks in the acquisition and consolidation of novel spoken words. *Brain and Language*, 167, 44–60. <https://doi.org/10.1016/j.bandl.2016.05.009>
- Vigliocco, G., Vinson, D. P., Lewis, W., & Garrett, M. F. (2004). Representing the meanings of object and action words: The featural and unitary semantic space hypothesis. *Cognitive Psychology*, 48(4), 422–488. <https://doi.org/10.1016/j.cogpsych.2003.09.001>
- Voss, J. L., & Federmeier, K. D. (2011). FN400 potentials are functionally identical to N400 potentials and reflect semantic processing during recognition testing. *Psychophysiology*, 48(4), 532–546. <https://doi.org/10.1111/j.1469-8986.2010.01085.x>
- West, W. C., & Holcomb, P. J. (2000). Imaginal, semantic, and surface-level processing of concrete and abstract words: An electrophysiological investigation. *Journal of Cognitive Neuroscience*, 12(6), 1024–1037. <https://doi.org/10.1162/08989290051137558>
- Zechmeister, E. B., Chronis, A. M., Cull, W. L., D'Anna, C. A., & Healy, N. A. (1995). Growth of a functionally important lexicon. *Journal of Reading Behavior*, 27(2), 201–212. <https://doi.org/10.1080/10862969509547878>

Appendix

Table A1

Novel Words Used in the Nonword Repetition Task

1 Syllable		2 Syllables		3 Syllables		4 Syllables	
Word	IPA	Word	IPA	Word	IPA	Word	IPA
naib	naib	tay-vock	tervak	chee-noy- taub	ʃiːnoitaub	vay-tah- chai-doyp	veitaɪʃaɪdoip
voup	voup	cho-vag	ʃʊvæg	nai-cho- veib	naɪʃʊveib	da-vo-noy- cheeg	dævoʊnoɪʃiːg
touge	taudʒ	va-chipe	væʃaɪp	doy-tau- vab	doɪtaʊvæb	nai-choy- tau-vube	naɪʃɔɪtaʊvub
doif	doif	noi-towf	noitaʊf	tae-voy- chaig	teɪvoɪʃaɪg	ta-vah- chee-naig	tævaɪʃaɪnaɪg

Note. IPA = International Phonetic Alphabet transcription.

Table A2

Novel Words Used in Both Experiments

Word	IPA	Word	IPA	Word	IPA	Word	IPA	Word	IPA
baab	bæb	guz	guz	laig	laɪg	pers	pɜːʃ	veeg	vɪg
bawsh	baʊʃ	haum	haʊm	laip	leɪp	pite	pait	vik	vaɪk
bawv	baʊv	heg	heɪg	lal	leɪl	pouk	paʊk	vod	voʊd
beel	biːl	hek	hɪk	lauk	laʊk	pous	paʊs	vosh	voʊʃ
bez	bɛz	hep	hep	lav	lɒv	puz	pʌz	vud	vʌd
boit	bɔɪt	hez	hez	leet	liːt	raub	raʊb	vush	vʌʃ
bok	bɒk	hig	haɪg	lesh	leʃ	rauch	raʊʃ	waich	waɪʃ
booj	budʒ	huth	hʌθ	lev	leɪv	reb	reɪb	werg	wɜːrg
boub	boʊb	jaed	dʒæd	lieb	laɪb	reesh	riːʃ	wesh	wɛʃ
bov	bɒv	jaf	dʒæf	loing	lɔɪŋ	reet	riːt	wib	wɪb
bown	boʊn	jawch	dʒaʊʃ	looz	lʌz	routh	raʊθ	wob	wɒb
chaip	ʃaɪp	jawsh	dʒaʊʃ	loth	loʊθ	ruch	ruːʃ	woin	wɔɪn
chak	ʃæk	jeng	dʒɛŋ	maich	maɪʃ	taef	tæf	wone	wʊn
chath	ʃæθ	jep	dʒɛp	mez	mɛz	tawk	taʊk	wook	wʊk
chud	ʃʌd	joog	dʒuːg	mide	maɪd	taz	tæz	wooth	wuθ
daek	daɪk	joon	dʒʌn	miv	mɪv	teg	tɛg	wop	wɒp
daep	daɪp	jurg	dʒɜːrg	moog	mʊg	teib	teɪb	wus	wʌs
dag	dæg	kais	kaɪz	mook	mʊk	thaep	θeɪp	yab	jab
daib	daɪb	kaj	kædʒ	mub	mʌd	thawp	θɒp	yaj	jædʒ
dawch	daʊʃ	kaub	kaʊb	muz	mʌz	theek	θɪk	yeb	jɛb
deav	diːv	kawn	kaʊn	naen	neɪn	theesh	θiːʃ	yiv	jɪv
deech	diːʃ	kawsh	kaʊʃ	naf	næf	theig	θeɪg	yiz	jɪz
deet	diːt	keeb	kɪb	naug	naʊg	therg	θɜːrg	yut	jʊt

Table A2*Novel Words Used in Both Experiments (Continued)*

Word	IPA	Word	IPA	Word	IPA	Word	IPA	Word	IPA
deech	dɪʃ	kawsh	kɑʃ	naf	næf	theig	θeɪg	yiz	jɪz
deet	dit	keeb	kib	naug	naʊg	therg	θɜrg	yut	jut
douth	douθ	keek	kik	nauk	naʊk	thoos	θus	zaeck	zeɪk
fawz	fɔz	keet	kit	naz	næz	thov	θaʊv	zeem	zim
fef	fef	kerd	kird	neg	neɪg	thuf	θʌf	zeep	zip
foug	foʊg	kern	kɛrn	nerb	nɜrb	thum	θum	zood	zud
gaib	gaɪb	kersh	kɜʃ	nerz	nɜrz	thup	θʌp	zub	zub
gak	geɪk	kes	kɛs	neth	nɛθ	tij	tɪdʒ	zut	zʌt
geb	geb	kis	kais	noib	nɔɪb	tooj	tudʒ	zuv	zuv
geel	gil	koag	koʊg	nouch	naʊʃ	toth	tɔθ		
geep	gip	kob	koʊb	nuk	nʌk	toud	taʊd		
gen	gen	koi	kɔɪs	pab	pæb	toush	toʊʃ		
geth	geθ	koob	kub	paug	pæg	tuz	tʌz		
gime	gaim	koov	kuv	paus	paʊz	vaing	væɪŋ		
gom	goom	kouf	koʊf	pauv	pɔv	vaip	vaɪp		
goot	gut	kuth	kʌθ	pawg	paʊg	vath	veɪθ		
goz	gaʊz	laeb	lɛb	pawv	paʊv	vave	veɪv		

Note. IPA = International Phonetic Alphabet transcription.**Table A3***Novel Words Unique to Each Experiment*

Experiment 1: Nouns				Experiment 2: Verbs			
Word	IPA	Word	IPA	Word	IPA	Word	IPA
chab	tʃæb	pieg	paɪg	baif	beɪf	peig	peɪg
chun	tʃʌn	powf	paʊf	bis	bɪs	pofe	poʊf
dooth	duθ	tav	teɪv	gov	goʊv	raz	ræz
doud	dʊd	tawd	taʊd	hauk	haʊk	voos	vʊs
douj	dʊdʒ	teep	tɪp	keeg	kɪg	woup	waʊp
duth	dʌθ	tez	teɪz	kos	kɔs	yaut	jaʊt
mobe	moʊb	thej	θedʒ	moob	mʊb	yem	jʌm
nuf	nɔf	toob	toʊb	nuff	naʊf	yez	jeɪz
nup	nʌp	yeez	jɪz	pawf	pɔf	zus	zʌs

Note. IPA = International Phonetic Alphabet transcription.

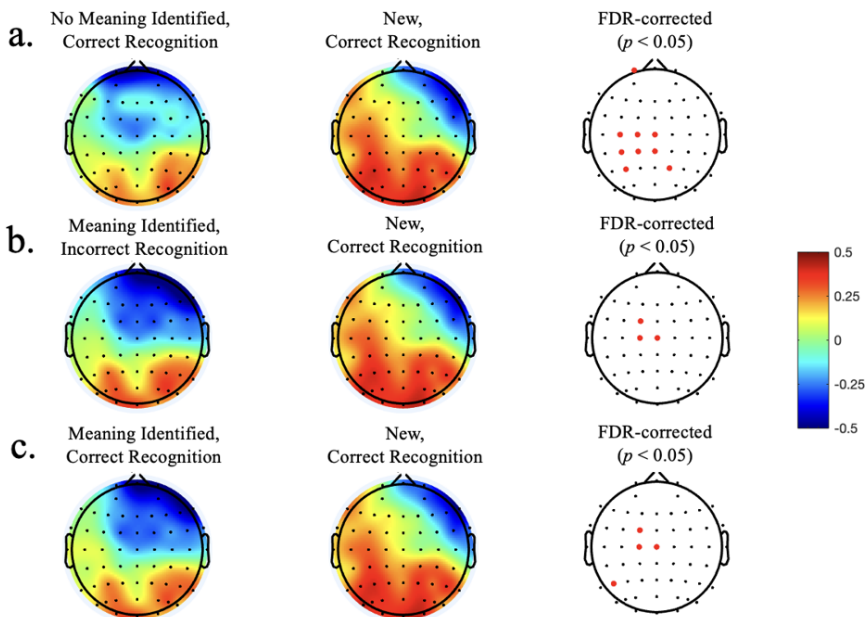
Table A4*Recognition Accuracy in the Recognition Task by Word Status for Each Experiment*

Condition	Experiment 1: Nouns		Experiment 2: Verbs	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Meaning Identified	0.51	0.50	0.48	0.50
No Meaning Identified	0.53	0.50	0.44	0.50
Old (<i>above combined</i>)	0.52	0.50	0.47	0.50
<i>New</i>	0.61	0.49	0.61	0.49

Note. Unlike *A'*, these values do not account for both hits and false alarms and therefore do not provide a bias-free measure of discrimination; they are provided here for descriptive purposes only.

Figure A1

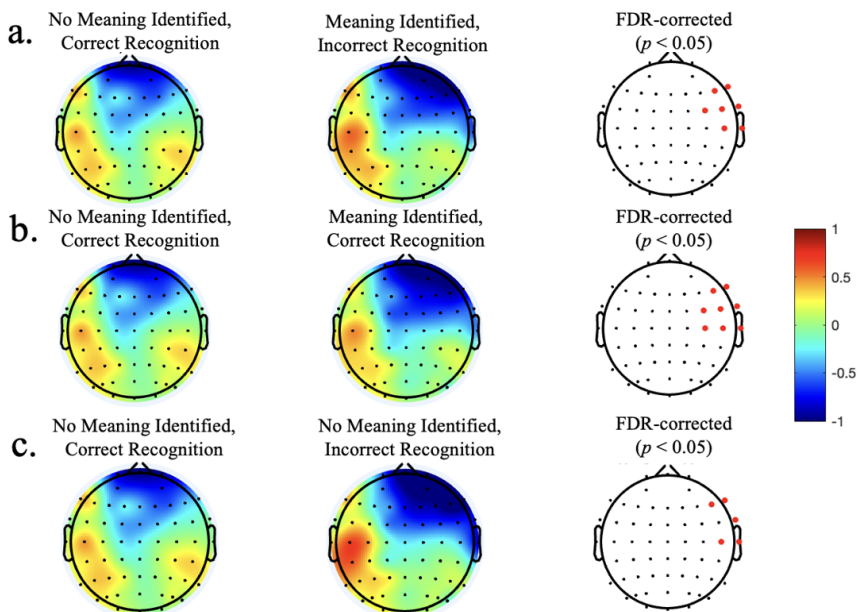
Scalp Maps of Nouns Representing Significantly Different Conditions from 30 to 170 ms after Target Word Onset



Note. Significant differences found between a) No Meaning Identified, Correct Recognition b) Meaning Identified, Incorrect Recognition, and c) Meaning Identified, Correct Recognition compared to New, Correct Recognition novel words from 30 to 170 ms after target word onset. Increases in ERP amplitude are represented in red, and decreases in ERP amplitude are represented in blue. Electrodes identified as significant by the cluster-based permutation test are highlighted in red on the far right scalp map (FDR-corrected p -values $< .05$).

Figure A2

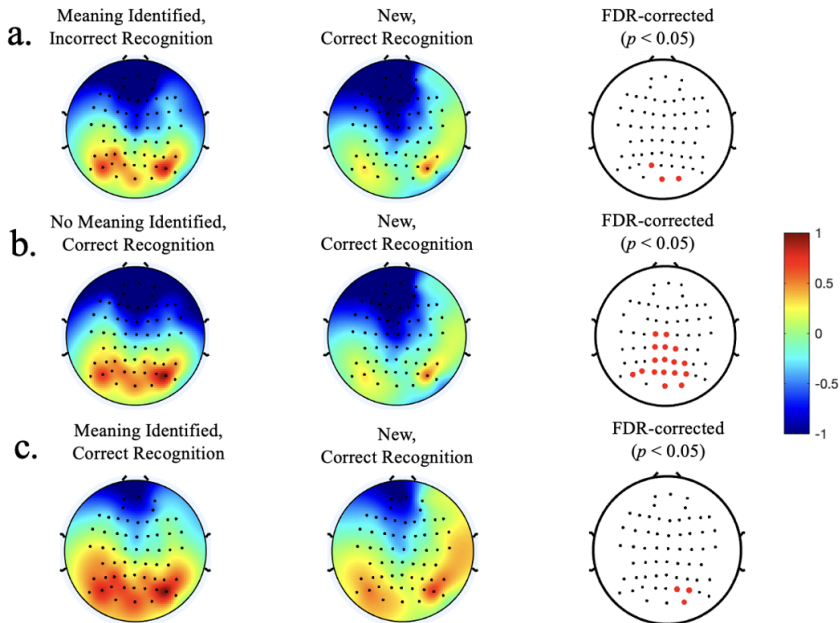
Scalp Maps of Nouns Representing Significantly Different Conditions from 350 to 550 ms after Target Word Onset



Note. Significant differences found between a) No Meaning Identified, Correct Recognition and Meaning Identified, Incorrect Recognition, b) No Meaning Identified, Correct Recognition and Meaning Identified, Correct Recognition, and c) No Meaning Identified, Correct Recognition and No Meaning Identified, Incorrect Recognition from 350 to 550 ms after target word onset. Increases in ERP amplitude are represented in red, and decreases in ERP amplitude are represented in blue. Electrodes identified as significant by the cluster-based permutation test are highlighted in red on the far right scalp map (FDR-corrected p -values $< .05$).

Figure A3

Scalp Maps of Verbs Representing Significantly Different Conditions from 350 to 550 ms after Target Word Onset



Note. Significant differences found between a) Meaning Identified, Incorrect Recognition, b) No Meaning Identified, Correct Recognition, and c) Meaning Identified, Correct Recognition compared to New, Correct Recognition novel words from 350 to 550 ms after target word onset. Increases in ERP amplitude are represented in red, and decreases in ERP amplitude are represented in blue. Electrodes identified as significant by the cluster-based permutation test are highlighted in red on the far right scalp map (FDR-corrected p -values $< .05$).

Table A5

Average Number of Trials Analyzed per Condition in the Recognition Task for Each Experiment

Condition		Experiment 1: Nouns		Experiment 2: Verbs	
		<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Old Words	Meaning Identified, Correct Recognition	34	10	35	8
	Meaning Identified, Incorrect Recognition	33	9	36	7
	No Meaning Identified, Correct Recognition	20	7	23	7
	No Meaning Identified, Incorrect Recognition	21	7	23	9
New Words	New, Correct Recognition	43	14	48	15

Note. Due to our research questions, there was an imbalanced number of new and old words of interest in the Recognition Task in both Experiment 1 (Nouns) and 2 (Verbs).