

EMPIRICAL STUDY

Learning Novel Word Meanings: An ERP Study on Lexical Consolidation in Monolingual, Inexperienced Foreign Language Learners

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Abstract: Novel word learning and consolidation was studied in inexperienced language learners, to conceptually replicate and extend a similar study in experienced learners by Bakker, Takashima, Van Hell, Janzen, and McQueen (2015). Participants learned definitions for novel words on Day 1 and for another set of novel words on Day 2. Brain potentials collected in a semantic relatedness task revealed that learned words elicited a late positive component (LPC) priming effect after 24 hours but not on the day of learning. On Day 8, all previously learned words elicited LPC priming effects, but failed to modulate the N400. While LPC modulation emerged immediately after learning in the previous study of experienced learners, novel word meanings were found lexicalized only on Day 2 for inexperienced learners. Together, the findings suggest that novel word meaning lexicalization is gradual, and that prior language learning experience speeds up the process.

Keywords word learning; offline consolidation; semantic integration; event-related potentials; late positive component; N400

Introduction

We encounter novel words on a regular basis in our daily life, such as when we learn internet slang words, or a new language. In adulthood the human

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brain is capable of acquiring and memorizing new words rapidly. Research has revealed that offline consolidation (e.g., during overnight sleep) enables recently acquired novel words to achieve representations resembling more that of existing words. This study examined the acquisition of novel words paired with novel meanings and focused on semantic integration and the role of consolidation at three time points: immediately, 1 day, and 1 week after learning.

Background Literature

Established upon connectionist models in learning and memory (McClelland, McNaughton, & O'Reilly, 1995), the Complementary Learning Systems (CLS) theory was adapted to word learning by Davis and Gaskell (2009). This model entails two stages: rapid initial familiarization and slow lexical consolidation. The initial stage is a rapid process of encoding word information as an episodic memory trace, supported by the hippocampal system and related areas in the medial temporal lobe. In the second stage, memories about word information achieve stable and longer-term neocortical representations following a period of offline consolidation. Novel words are thus thought to undergo a postlearning consolidation process during which hippocampal connections decay and neocortical connections are strengthened. Sleep is an important period during which offline consolidation is thought to occur (for a review, see Born & Wilhelm, 2012). Further, the CLS theory claims that during the rapid initial familiarization stage, learners can explicitly recall the newly learned word information, immediately after exposure. However, these novel words are not yet integrated into the lexical network, and thus cannot interact with existing words. Only after a period of offline consolidation (e.g., overnight sleep), during which novel words start becoming integrated into the lexical network, can newly learned words interact dynamically with existing word representations.

A substantial body of behavioral (e.g., Dumay & Gaskell, 2012; Tamminen, Payne, Stickgold, Wamsley, & Gaskell, 2010) and neuroimaging (e.g., Bakker-Marshall et al., 2018; Davis, Di Betta, Macdonald, & Gaskell, 2008; Takashima, Bakker, van Hell, Janzen, & McQueen, 2014, 2017) research supports the role of offline consolidation in spoken word learning. For instance, in Tamminen et al. (2010) participants were divided into a wake and a sleep group, and learned novel spoken words (e.g., *cathedruke*) that partially overlapped phonologically with existing words (*cathedral*). Performance on word recognition and recall improved overnight, but not during the day. Additionally, analyses of sleep EEG data demonstrated a positive association between sleep spindle activity and overnight integration of novel spoken words into existing lexical knowledge. Evidence for the role of offline consolidation during sleep has also been

obtained for word learning in the visual domain (Bowers, Davis, & Hanley, 2005; Ellenbogen, Hulbert, Jiang, & Stickgold, 2009). More recently, Bakker, Takashima, van Hell, Janzen, and McQueen (2014) demonstrated that consolidation occurs both within and across modalities. Specifically, 24 hours after initial exposure, novel words acquired in the auditory modality entered into competition with phonologically similar existing words, in both an auditory modality task (pause detection task) and a visual modality task (semantic decision task). This competition effect remained robust after 7 days. For novel words learned in the visual modality, the lexical competition effect emerged 24 hours after learning, whereas lexical competition in the auditory modality emerged 7 days later.

The novel word learning and consolidation research discussed above focused on learning phonological or orthographic information, and excluded semantics. A separate line of research has investigated the integration of novel word meanings with existing semantic knowledge, and compared performance before and after an offline consolidation period using semantic priming as a measure of lexical consolidation (e.g., Bakker, Takashima, van Hell, Janzen, & McQueen, 2015; Kurdziel & Spencer, 2016; Tamminen & Gaskell, 2013). Semantic priming (Meyer & Schvaneveldt, 1971) usually manifests in the form of faster and more accurate responses to a target word (e.g., *cat*) preceded by a semantically related prime (e.g., *dog*) as compared to an unrelated prime (e.g., *table*). The assumption is that the prime word activates semantically related concepts, which accelerates the lexical retrieval process of a semantically related target word. The semantic priming task thus provides an online measure to examine the offline consolidation of novel word meanings, based on the hypothesis that only after novel word meanings have been integrated into the lexical network, a semantic priming effect can emerge. For example, in a behavioral study that examined offline consolidation and semantic integration, Tamminen and Gaskell (2013) had participants learn novel words with novel meanings. When the authors presented newly learned words as primes before semantically related or unrelated existing target words, a semantic priming effect was observed after a 24-hour delay. This suggests that offline consolidation aided the integration of new words into semantic memory.

In addition to behavioral measurements (e.g., Kurdziel & Spencer, 2016; Tamminen & Gaskell, 2013), the technique of event-related potentials (ERPs) has been used to examine neural activity associated with lexical consolidation of newly learned words (e.g., Bakker et al., 2015; Borovsky, Kutas, & Elman, 2010; Kaczer et al., 2018; Meade, Midgley, Dijkstra, & Holcomb, 2018). ERPs reflect averaged electrical brain activity time-locked to the onset of a

repeated event (e.g., word presentation) and capture neurocognitive processes as they unfold over time, with millisecond precision. An important electrophysiological marker of lexical-semantic access is the N400, a negative-going ERP component that peaks around 400 milliseconds post-stimulus onset. The N400 has ubiquitously been found to be less negative when a target stimulus is preceded by a semantically related prime word relative to an unrelated prime word. This makes the N400 a good candidate to study consolidation in word learning through the lens of semantic priming. Specifically, if a newly acquired word's meaning has been consolidated, the N400 responses to the novel word should be sensitive to the semantic relatedness of the preceding prime. The N400 response to word stimuli is often followed by a late positive component (LPC), which is an extended posterior positivity peaking between 500 and 700 milliseconds after target word onset. A modulation of the LPC is found when the prime and the target word are semantically related (LPC priming effect; e.g., Bakker et al., 2015; Hoshino & Thierry, 2012; Kandhadai & Federmeier, 2010) as compared to when prime and target are unrelated. In the novel word learning and semantic processing literature, the N400 is taken to index relatively automatic aspects of semantic access, whereas LPC modulation is associated with more strategic/explicit and controlled aspects of semantic retrieval, integration and revision (e.g., Bakker et al., 2015; Deacon, Hewitt, Yang, & Nagata, 2000; Fang & Perfetti, 2017; Hoshino & Thierry, 2012; Kandhadai & Federmeier, 2010; Rohaut et al., 2015).

Using ERPs to examine the learning of novel word meanings, Bakker et al. (2015) had Dutch participants learn printed novel words (e.g., *pamat*) that were paired with novel definitions (e.g., *a pamat is a cat that has stripes and is bluish grey*). Participants were trained on one set of novel words and existing Dutch words on Day 1 and another set on Day 2. Immediately after word learning on Day 2, participants' ERP responses to words trained on Day 1 and Day 2 were recorded when performing a semantic priming task: Novel words trained on Day 1 and Day 2, as well as existing words (controls), were preceded by semantically related or unrelated primes. ERP results showed a frontal LPC semantic priming effect immediately after learning, and a robust posterior LPC semantic priming effect 24 hours after learning, reflecting a more controlled, and nonautomatic semantic retrieval. However, no N400 semantic priming effects were observed (and thus there was no evidence for more automatic semantic retrieval), regardless of whether novel words were trained on Day 1 or Day 2. Bakker et al. (2015) concluded that controlled retrieval processes enabled semantic priming on Day 2 even when words are not yet fully lexicalized.

The findings thus suggest that semantic integration of newly learned words might be a more gradual process.

The Current Study

Extending the research discussed above, we investigated two main questions. First, after a longer period of offline consolidation—that is, 1 week after learning (in addition to 24 hours after learning)—can the activation of novel word meaning achieve more automaticity, indexed by a reliable N400 effect? Using behavioral measurements, Tamminen and Gaskell (2013) found that meaningful novel words elicited a stronger semantic priming effect on Day 8 compared to Day 2. If an extended period of offline consolidation further enhances semantic integration, we expect that semantic activation of novel words in related prime-target pairs will become more automatic 7 days after initial exposure, yielding an N400 semantic priming effect.

Second, although not explicitly discussed, the Dutch participants tested in Bakker et al. (2015), all undergraduate students, were highly experienced language learners. In the Netherlands, English language education is compulsory in primary and secondary education. Moreover, the level of secondary education required for access to university entails at least 2 years of instruction in two other modern languages (typically French and German). As a result, Bakker et al. (2015) participants were all experienced foreign language learners, and highly fluent in at least one foreign language, English. Previous studies have found that bilinguals demonstrated better retention of newly learned words than monolinguals (e.g., Kaushanskaya, 2012; Kaushanskaya & Marian, 2009; Van Hell & Candia Mahn, 1997). Bakker et al. (2015) findings may thus be unique for multilingual participants with extensive experience learning foreign languages, and may not generalize to all learners, including learners with little foreign language learning experience. This question was addressed in the present study by testing learners who have little experience with learning foreign languages and who are functionally monolingual.

Taken together, the current study sought to conceptually replicate and extend the findings of Bakker et al. (2015), and investigate novel vocabulary learning in monolingual English speakers with minimal foreign language learning experience. In addition, we examined whether an extended period of offline consolidation would further enhance semantic integration by testing learners immediately after learning and one day after learning, as well as one week after learning.

Methods

Participants

Thirty English native speakers ($M_{\text{age}} = 19.22$ years, $SD = 1.41$; six males, 23 females), all right-handed undergraduate students enrolled at a large public university in the United States, were tested, and received course credits for participation. Participants had no history of neurological or language-related disorders, and reported normal or corrected-to-normal vision and normal hearing. Four participants discontinued participation after Day 1, and three more after Day 2, for reasons unrelated to the purpose of the experiment. All participants were raised monolingually. They were functionally monolingual and had limited knowledge of languages other than English, as determined by the prescreening procedure during recruitment, and confirmed by an in-house Language History Questionnaire. Participants who reported having taken second-language classes prior to college entry ($N = 22$) rated their average L2 proficiency as 3.39 ($SD = 2.54$) and those who reported having taken third-language classes ($N = 4$) rated their average L3 proficiency as 3.69 ($SD = 0.94$), on a 10-point scale ranging from 1 (*very low*) to 10 (*perfect*). Participants who returned for Day 2 ($N = 26$) reported having regular amounts of sleep ($M = 6.86$ hours, $SD = 1.35$), and 73% reported having normal or higher than usual sleep quality the night before Day 2, as assessed by a postsleep questionnaire when participants returned on Day 2.

Materials

Stimuli consisted of 80 words: two lists of 20 novel words and two lists of 20 existing high-frequency English words (see Supporting Information S1). Novel word stimuli were nonderivational pseudowords, selected from Deacon, Dynowska, Ritter, and Grose-Fifer's (2004) stimuli. All were pronounceable and orthographically legal in English, had a mean word length of 5.78 letters (range: 4–8 letters), and had no orthographic neighbors, according to the CLEARPOND database (Marian, Bartolotti, Chabal, & Shook, 2012). Two lists of 20 novel definitions were created to assign meanings to the novel words. Following Bakker et al. (2015), each definition consisted of one existing object (e.g., *a pair of scissors*) as the base for the novel word (here: *tupradu*), paired with two unconventional features (e.g., *that is operated by two people* and *can cut rocks*). The two lists of 20 existing English words had a mean length of 5.58 letters (range: 3–8 letters) and a mean lexical frequency of 49.83 per million words ($SD = 42.39$; CLEARPOND database). Each existing English word (e.g., *oven*) was paired with its definition (e.g., *an enclosed chamber used for baking, heating, or drying*); existing words and their meanings were presented along with novel words and their meanings during learning to control for exposure

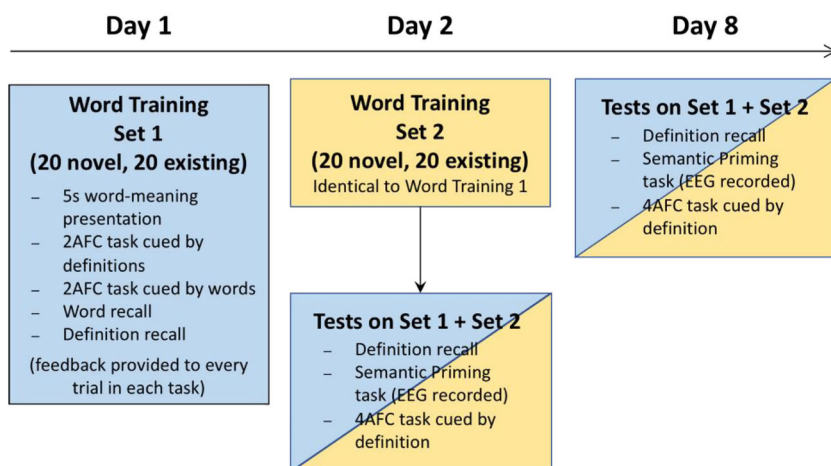


Figure 1 Schematic overview of training and testing tasks. [Color figure can be viewed at wileyonlinelibrary.com]

(see Procedure). The two lists of 20 existing English words did not differ in lexical frequency [$t(38) = 0.20, p = .84$]. All four lists of novel and existing words did not differ in word length [$F(3, 76) = 0.61, p = .61$].

Prime words used in the semantic priming task were existing English words (mean length = 5.58 letters, $SD = 1.67$; mean frequency = 42.77 per million words), selected from the Florida Free Association Norms Database (Nelson, McEvoy, & Schreiber, 2004) with values of prime-target forward association strength provided. Two semantically related prime words were chosen for each to-be-learned word. For each novel word (e.g., *tupradu*), the base word (here: *scissors*) in its assigned novel definition was used to search for semantically related cue words as primes (here: *shears* and *clippers*). Importantly, these two selected prime words did not appear in the corresponding definition of that word. For each existing English word, two semantically related prime words were selected. The mean forward association (i.e., prime-to-target) strength was .34 ($SD = .24$) for the novel words' base words and .34 ($SD = .21$) for existing English words. For each to-be-learned word, two semantically unrelated primes were assigned by pseudo-randomizing prime words.

Procedure

The experiment included three sessions: Day 1, Day 2, and Day 8 (see Figure 1). The training and testing procedures on Day 1 and Day 2 were

similar to Bakker et al. (2015); note that Bakker et al. (2015) did not include Day 8. On Day 1, participants received word training on one list of 20 novel words and one list of 20 existing English words. On Day 2, they were trained on the other list of 20 novel words and the other list of 20 existing English words, following identical word training procedures (see Word Training). Immediately after word training on Day 2, the semantic priming task was administered while EEG signals were recorded (see Semantic Priming Task). Two additional behavioral memory tests were administered to assess participants' memorization of trained words (see Memory Tests). Upon their return on Day 8, the identical EEG-recorded semantic priming task and behavioral memory tests were administered.

Word Training

The training procedure (see Figure 1) was similar to Bakker et al. (2015), which started with a 5-second presentation of each word together with its definition. Next, four training tasks were administered, in a fixed order (approximate time to complete each task is presented between parentheses): (a) two-alternative-forced-choice (2AFC) task cued by definitions (~8 minutes). Participants were provided a definition and needed to select the matched word from two word-choices; there were three trials for each definition; (b) 2AFC task cued by words (~10 minutes). Participants were provided a word and needed to select the matched definition from two definition choices; there were three trials for each word; (c) word recall task cued by definitions (~12 minutes). Participants typed in the word matched to the presented definition; and (d) definition recall task cued by words (~20 minutes). Participants typed in the definition that matched the presented word. Responses in all tasks were made via keyboard. There was no response time limit during these four tasks. After each response, the correct answer was presented for 3 seconds to provide feedback. The word training procedure on Day 1 and Day 2 was identical.

Memory Tests

Memory tests also followed the procedure of Bakker et al. (2015), except that Day 8 testing was added. Immediately after word training on Day 2, a definition recall task was administered without feedback, presenting all 80 words (40 novel and 40 existing English words) learned during Day 1 and Day 2. This task served to assess memory but also to reactivate words trained on Day 1 in order to reduce potential differences in perceptual processing between Day 1 and Day 2 words due to recency of exposure (see also Bakker et al., 2015). Participants were presented with all 80 words and were instructed to recall and

type in the definition of each word. This same task was administered on Day 8. After completion of the semantic priming task (described below) on Day 2 and Day 8, a four-alternative-forced-choice (4AFC) task cued by definition was administered, in which participants selected the word that matched with the presented definition from four word-choices; all 80 words were presented and no feedback was provided. Since this task was easier than the definition recall task, it also serves as an additional check to confirm that learning novel words on Day 1 and Day 2 had been successful, and that no excessive forgetting had occurred for Day 1 words. There was no response time limit in both memory tests; on average, the definition recall and the 4AFC tasks took 25 and 12 minutes, respectively.

Semantic Priming Task

EEG was recorded during the semantic priming task, following Bakker et al. (2015) procedure. Each word trained on Day 1 and Day 2 served as target word, and was paired with four prime words: two semantically related and two unrelated to the target word. Each target word occurred only once in each block, and there were four blocks of 80 prime-target trials. Each trial started with a 600 milliseconds fixation cross, then the prime word was presented for 250 milliseconds, followed by a blank screen for 250 milliseconds and the target word for 1,000 milliseconds. The response screen with the question (“Semantically related?”) then appeared and remained on the screen for 2000 milliseconds or until the participant pressed the button. During this time participants evaluated whether the prime and target were semantically related or not by pressing the left or right button on a button box. After each trial, a smiley face showed up for 1000 milliseconds, during which participants could blink and rest their eyes before the onset of the next trial. They also took a break between blocks.

EEG Data Acquisition and Preprocessing

Participants were seated in a comfortable chair in a sound-attenuated dimmed room, approximately three feet away from a computer monitor on which the stimuli were displayed. An elastic cap (BrainProducts ActiCap, Germany) with 31 active Ag/AgCl electrodes was placed on the head: Five electrodes located along the midline (Fz, FCz, Cz, Pz, Oz) and 26 electrodes on the lateral sites (FP1/2, F7/8, F3/4, FC5/6, FC1/2, T7/8, C3/4, CP5/6, CP1/2, P7/8, P3/4, PO9/10, O1/2). Additional electrodes were placed above and below the left eye, and at the outer canthus of each eye, to screen for ocular artifacts. Electrode impedances were kept below 10 k Ω . EEG signals were amplified by a NeuroScan SynampsRT amplifier using a .05–100 Hz bandpass filter (first-order

Butterworth with a 6 dB/octave roll-off), and digitized with a 500-Hz sampling rate. Electrodes were referenced to a vertex reference (electrode FCz) and rereferenced offline to an average of the left and right mastoids.

ERPLAB (Lopez-Calderon & Luck, 2014) was used for the preprocessing and measurement of ERP data. An offline 30-Hz half-amplitude low-pass filter (12 dB/octave roll-off) was applied to the continuous EEG data. ERPs, time-locked to the onset of the target word, were averaged offline for each participant at each electrode site in each experimental condition, from 100 milliseconds prior to stimulus onset (prestimulus baseline) to 1000 milliseconds after stimulus onset.

For each EEG dataset, artifact detection was carried out using ERPLAB's moving window peak-to-peak artifact detection function using a voltage threshold of 100 μ V; visual inspection was used to verify the effectiveness of this detection method and parameters were adjusted as necessary to optimize rejection. Trials contaminated with eye or movement artifacts were excluded from data analyses (10.55% and 9.43%, respectively, for Day 2 and Day 8). For Day 2 data, the average number of included trials were: 36.22 trials (range = 28–40) for remote novel words in the related condition, 35.90 trials (range = 23–40) for remote novel words in the unrelated condition, 36.09 trials (range = 24–40) for recent novel words in the related condition, 36.70 (range = 28–40) for recent novel words in the unrelated condition, 35.04 trials (range = 25–40) for remote existing words in the related condition, 34.90 trials (range = 26–40) for remote existing words in the unrelated condition, 35.22 trials (range = 23–40) for recent existing words in the related condition, and 34.74 trials (range = 26–40) for recent existing words in the unrelated condition. For Day 8 data, average number of included trials were: 36.41 trials (range = 30–40) for remote novel words in the related condition, 36.70 trials (range = 27–40) for remote novel words in the unrelated condition, 36.27 trials (range = 28–40) for recent novel words in the related condition, 36.20 (range = 27–40) for recent novel words in the unrelated condition, 34.68 trials (range = 26–40) for remote existing words in the related condition, 34.90 trials (range = 24–40) for remote existing words in the unrelated condition, 35.18 trials (range = 24–40) for recent existing words in the related condition, and 34.45 (range = 26–40) for recent existing words in the unrelated condition.

Data Analyses

For behavioral data, accuracy scores on the definition recall and 4AFC tasks were analyzed in a Word-type (novel, existing) by Condition (remote, recent)

repeated-measures ANOVA, separately so for Day 2 and Day 8. The remote and recent conditions refer to the words trained on Day 1 and Day 2, respectively. Semantic relatedness judgment accuracy scores were submitted to a Word-type (novel, existing) by Condition (remote, recent) by Semantic relatedness (related, unrelated) repeated-measures ANOVA, separately so for Day 2 and Day 8. Only significant effects ($p < .05$) are reported. The complete descriptive statistics and behavioral ANOVA results for each task is reported in Supporting Informations S2 and S3, respectively. For all three behavioral tasks, all factors were treated as within-participant variables and when significant interactions with Word-type emerged, posthoc ANOVA tests were conducted by examining the effects separately for the novel words and the existing words, and critical p values were Bonferroni-corrected accordingly.

For EEG data, following Bakker et al. (2015), ERP analyses were conducted on mean amplitudes and the same time-windows were selected: 300–500 milliseconds for the N400 component and 500–700 milliseconds for the LPC component. For each time-window and separately for Day 2 and Day 8, both midline and laterality omnibus ANOVAs were computed with Condition (remote, recent), Word-type (existing, novel) and Relatedness (related, unrelated) as repeated measures. The midline ANOVA focused on midline electrodes (Fz, Cz, Pz). The laterality ANOVA included the factors anteriority (frontal, posterior) and laterality (right, left hemisphere); for these factors, electrodes were grouped into four regions of interest: right frontal (RF: F4, F8, FC2, FC6); left frontal (LF: F3, F7, FC1, FC5); right posterior (RP: CP2, CP6, P4, P8); left posterior (LP: CP1, CP5, P3, P7). A Greenhouse-Geisser correction was applied to analyses with more than one degree of freedom in the numerator. Only significant main effects and interaction effects involving the Relatedness factor ($p < .05$) are reported, which reflects theoretically relevant semantic priming effects.

To test *a priori*, and critical, hypotheses on lexical consolidation of novel words, planned tests were conducted on the Day 2 novel word EEG data to examine the simple main effect of Relatedness in the remote condition and in the recent condition separately. On Day 8, the distinction between remote and recent conditions (i.e., words learned on Day 1 and Day 2) is no longer critical, so these planned tests were conducted on Day 2 data only. Additionally, for all significant interactions with Relatedness, posthoc ANOVA tests were conducted, and critical p values were Bonferroni-adjusted. When a higher order interaction effect achieved significance, we did not report the significant main effects. The complete ERP ANOVA results are reported in Supporting Information S4.

Results

Behavioral Measurements

Twenty-six participants returned on Day 2, and 23 on Day 8. Because of computer malfunction, 4AFC word recognition data of two participants on Day 2 and one on Day 8 was lost. Therefore, analyses of the definition recall and the semantic relatedness judgment data are based on 26 (Day 2) and 23 participants (Day 8), and the 4AFC word recognition data on 24 and 22 participants (Day 2 and Day 8, respectively).

Definition Recall Task

Participants' accuracy score was calculated by assessing whether they recalled the object category (1/3) and two novel features (1/3 each) correctly. Word-type interacted with Condition on Day 2 ($F(1, 25) = 34.30, p < .001, \eta_p^2 = .58$) and Day 8 ($F(1, 22) = 9.45, p = .006, \eta_p^2 = .30$; see Figure 2A for mean accuracy scores). Posthoc tests showed that on Day 2, accuracy on words trained on Day 2 (recent) was higher than on words trained on Day 1 (remote), but this effect was more pronounced for novel words [$F(1, 25) = 33.59, p < .001, \eta_p^2 = .57; p_{\text{critical}} = .025$] than for existing words [$F(1, 25) = 6.76, p = .02, \eta_p^2 = .21; p_{\text{critical}} = .025$]. However, on Day 8, for novel words accuracy was higher for the remote than for the recent condition [$F(1, 22) = 8.27, p = .009, \eta_p^2 = .27; p_{\text{critical}} = .025$]; for existing words, accuracy was equally high across conditions [$F(1, 22) = 1.25, p = .28, \eta_p^2 = .05; p_{\text{critical}} = .025$].

4AFC Word Recognition Task

The main effect of Word-type was significant for Day 2 [$F(1, 23) = 18.62, p < .001, \eta_p^2 = .45$] and Day 8 [$F(1, 21) = 16.10, p < .001, \eta_p^2 = .43$; see Figure 2B]. Accuracy on existing words was higher than on novel words, although accuracy for novel words was still very high on Day 2 and Day 8 (93.5% and 90.4%). The effect of Condition was significant on Day 2 [$F(1, 23) = 7.29, p = .01, \eta_p^2 = .24$]: Participants were 1.9% more accurate in the recent than in the remote condition; this effect disappeared on Day 8 [$F(1, 21) = 0.03, p = .88, \eta_p^2 = .001$].

Semantic Relatedness Judgment Task

The pattern of performance was highly similar for Day 2 and Day 8, see Figure 2C. On Day 2, the main effect of Condition was significant [$F(1, 25) = 9.40, p = .005, \eta_p^2 = .27$]: Accuracy was higher for words trained on Day 1 (remote) than on Day 2 (recent). On Day 2, the Word-type \times

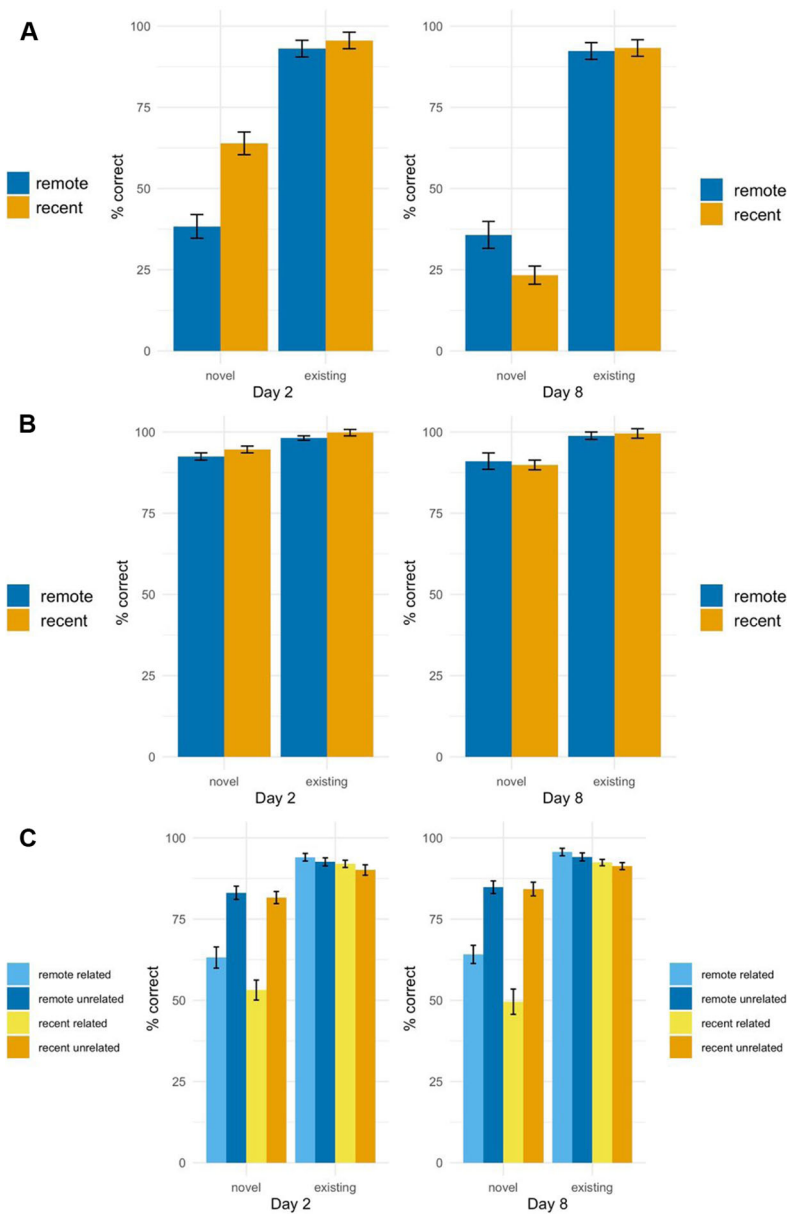


Figure 2 Mean accuracy scores on Definition Recall task (Panel A), 4AFC Word Recognition task (Panel B) and Semantic relatedness judgment task (Panel C). Error bars are $\pm SE$. [Color figure can be viewed at wileyonlinelibrary.com]

Relatedness interaction was also significant [$F(1, 25) = 55.71, p < .001, \eta_p^2 = .69$]. Posthoc tests showed that performance accuracy on related and unrelated trials was not different for existing words [$F(1, 25) = 1.74, p = .20, \eta_p^2 = .07; p_{\text{critical}} = .025$], but for novel words accuracy scores were higher for unrelated than for related trials [$F(1, 25) = 53.57, p < .001, \eta_p^2 = .68; p_{\text{critical}} = .025$]. This finding parallels Bakker et al. (2015) and Kaczer et al. (2018), who also found higher accuracy for unrelated than related trials in novel words.

On Day 8, the Condition \times Word-type \times Relatedness interaction was significant [$F(1, 22) = 7.18, p = .01, \eta_p^2 = .25$]. As is clear in Figure 2C, the pattern of results for Day 8 is nearly identical to Day 2 (where this interaction was marginally significant, $p = .06$). For existing words, accuracy on related trials was 1.3% higher than on unrelated trials [$F(1, 22) = 6.98, p = .01, \eta_p^2 = .24; p_{\text{critical}} = .025$]. For novel words, accuracy was 27.67% higher for unrelated than for related trials [$F(1, 22) = 51.62, p < .001, \eta_p^2 = .70; p_{\text{critical}} = .025$], a pattern also found on Day 2 and in Bakker et al. (2015) and Kaczer et al. (2018). For Day 8, accuracy for novel words is relatively low in the recent condition (and slightly lower than on Day 2), which appeared to drive the significant three-way interaction on Day 8 (that approached significance on Day 2).

One remarkable finding in the semantic relatedness judgments for novel words is the higher accuracy for unrelated trials than for related trials (no difference was observed for existing words). This is not an isolated finding, and has also been reported in novel word learning studies testing experienced Dutch multilingual learners (Bakker et al., 2015) and Spanish learners from Argentina (Kaczer et al., 2018). We propose that this converging pattern reflects the gradual lexicalization process of novel word meanings. As novel word meanings become integrated into the lexical network, the links between related concepts gradually emerge and are not yet fully established (as we will elaborate upon in the Discussion). When making a semantic judgment on the meanings of an existing word and a novel word, these emerging links induce higher response uncertainty and lower accuracy for semantic judgment in related trials relative to unrelated trials that do not have connecting links whatsoever. In existing words, links between semantically related words have been fully established; indeed, no accuracy differences were observed in semantic judgments for related and unrelated trials in existing words.

ERP Measurements

EEG data of two participants on Day 2 and one on Day 8 were discarded prior to statistical analyses, because of noisy channels. Day 2 data from one additional

participant was dropped because of high artifact rejection rate (>30%). The reported EEG data are based on 23 participants on Day 2 and 22 on Day 8. Following Bakker et al. (2015), ERP analyses were conducted on mean amplitudes and the same time-windows were selected: 300–500 milliseconds for the N400 component and 500–700 milliseconds for the LPC component. For each time-window, and separately for Day 2 and Day 8, omnibus Word-type \times Relatedness \times Condition midline and laterality ANOVAs were carried out. If Word-type interacted with Relatedness, we then conducted separate ERP analyses for novel words and for existing words. ERP waveforms are presented as follows: existing words on Day 2 (Figure 3A), existing words on Day 8 (Figure 3B), novel words on Day 2 (Figure 4A), and novel words on Day 8 (Figure 4B).

N400 Semantic Priming Effect on Day 2

Midline ANOVA. The omnibus midline ANOVA revealed a Word-type \times Relatedness \times Midline interaction effect [$F(2, 44) = 4.38, p = .02, \eta_p^2 = .17$]. Because of the significant interaction with Word-type, Relatedness \times Midline ANOVA tests were conducted separately for existing and novel words.

For existing words (see Figure 3A), the Relatedness main effect was observed [$F(1, 22) = 127.40, p < .001, \eta_p^2 = .85; p_{\text{critical}} = .025$]: The N400 was less negative-going when existing English target words (e.g., *elephant*) were preceded by a semantically related prime word (e.g., *giraffe*) relative to an unrelated prime (e.g., *sky*). For novel words tested on Day 2 (see Figure 4A), the Relatedness \times Midline ANOVA test in the N400 time-window yielded no significant effects involving the relatedness factor ($F_s < 1.44, p > .25, \eta_p^2 < .06; p_{\text{critical}} = .025$).

To test a priori, and theoretically critical, hypotheses on lexical consolidation of novel words (see section Data analyses), planned tests were conducted to examine the main effect of Relatedness in the remote and recent conditions separately. These tests confirmed that no N400 semantic priming effect emerged in the remote or recent conditions at midline ROIs ($F_s < 0.74, p > .40, \eta_p^2 < .03$).

Laterality ANOVA. The omnibus laterality ANOVA revealed a Relatedness \times Anteriority [$F(1, 22) = 7.45, p = .01, \eta_p^2 = .25$] and a Laterality \times Word-type \times Relatedness interaction [$F(1, 22) = 9.85, p = .005, \eta_p^2 = .31$].

To follow-up the former interaction, posthoc one-way Relatedness ANOVAs were conducted separately at frontal and posterior sites. The Relatedness effect was stronger in the posterior ROI [$F(1, 22) = 110.10, p < .001$,

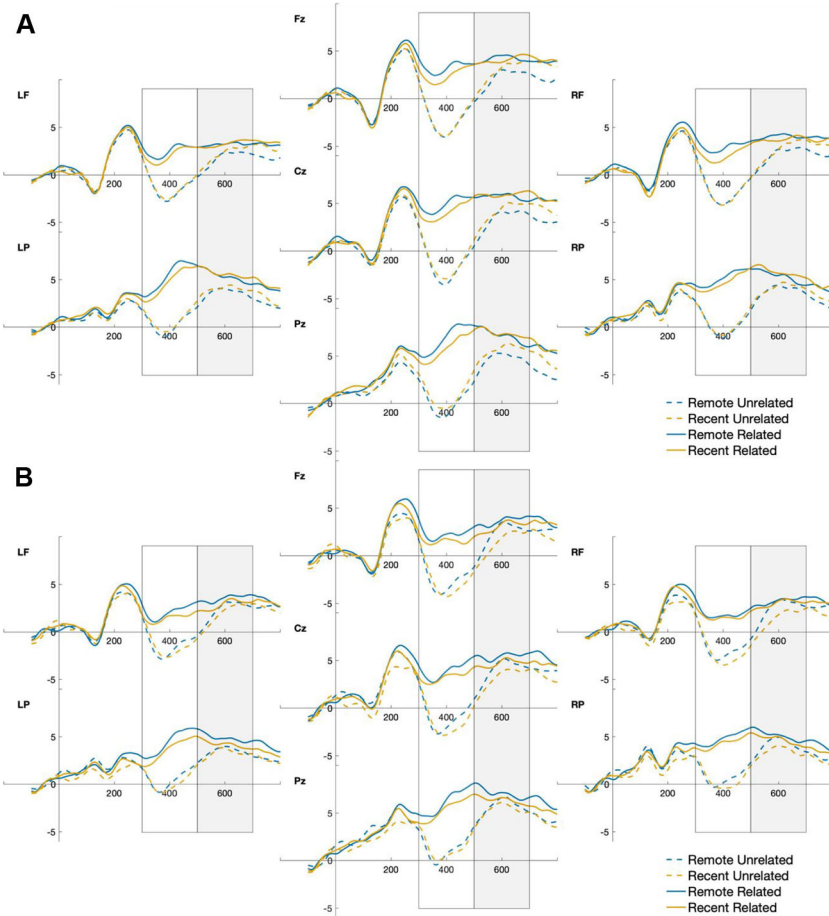


Figure 3 Semantic priming effects in existing English words on Day 2 (Panel A) and Day 8 (Panel B): ERPs (event-related potentials) time-locked to existing words preceded by a semantically related or unrelated prime word. For presentation purposes only, waveforms were filtered with a 15-Hz low-pass filter. [Color figure can be viewed at wileyonlinelibrary.com]

$\eta_p^2 = .83; p_{\text{critical}} = .025]$ than the frontal ROI [$F(1, 22) = 60.75, p < .001, \eta_p^2 = .73; p_{\text{critical}} = .025]$, which aligns with the classic topographic distribution of the N400. To follow-up on the latter Laterality \times Word-type \times Relatedness interaction effect, a Laterality \times Relatedness ANOVA was conducted for existing words and novel words separately. For existing words (see Figure 3A),

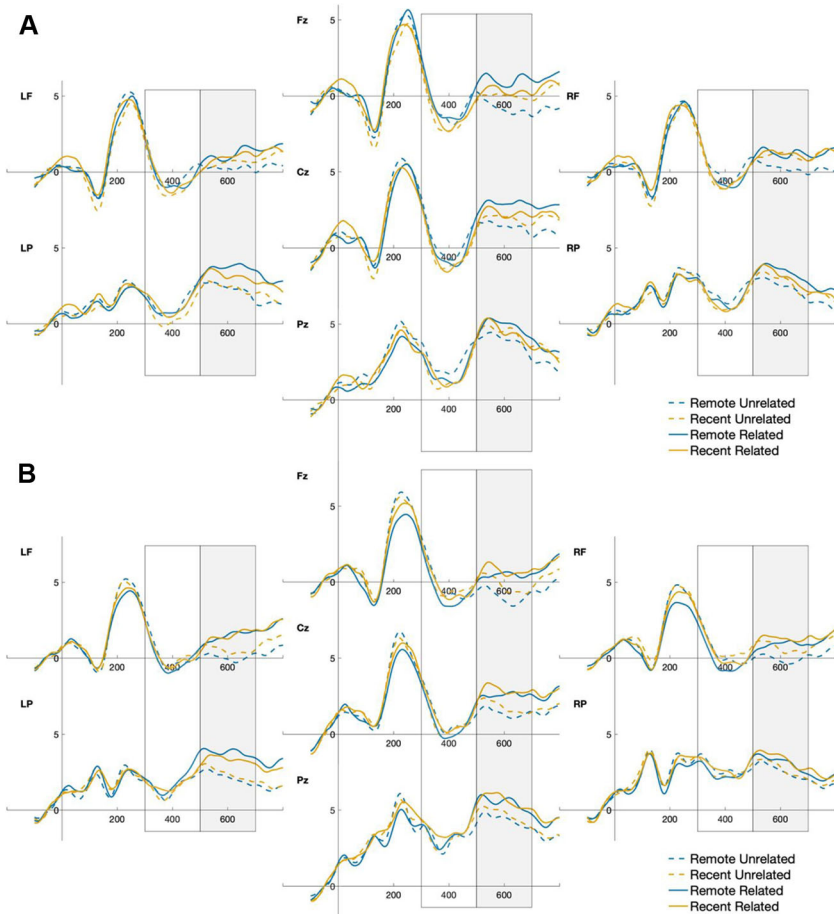


Figure 4 Semantic priming effects in novel words on Day 2 (Panel A) and Day 8 (Panel B): ERPs (event-related potentials) time-locked to novel words preceded by a semantically related or unrelated prime word. For presentation purposes only, waveforms were filtered with a 15-Hz low-pass filter. [Color figure can be viewed at wileyonlinelibrary.com]

the main effect of Relatedness [$F(1, 22) = 113.10, p < .001, \eta_p^2 = .83; p_{\text{critical}} = .025$] and the Laterality \times Relatedness interaction [$F(1, 22) = 6.37, p = .019, \eta_p^2 = .22; p_{\text{critical}} = .025$] were significant. Follow-up one-way ANOVA tests on the interaction effect revealed that the Relatedness effect emerged reliably in both hemispheres, but was slightly stronger for the right hemisphere [$F(1,$

22) = 115.20, $p < .001$, $\eta_p^2 = .84$; $p_{\text{critical}} = .013$] versus the left hemisphere [$F(1, 22) = 104.60$, $p < .001$, $\eta_p^2 = .83$; $p_{\text{critical}} = .0125$]. For novel words (see Figure 4A), no significant effects involving Relatedness emerged ($F_s < 3.86$, $p_s > .08$, $\eta_p^2 < .13$; $p_{\text{critical}} = .025$).

Planned tests were also conducted to examine the main effect of Relatedness in the remote and recent conditions separately; these confirmed that no N400 semantic priming effect emerged for novel words in the remote or recent conditions at lateral ROIs ($F_s < 1.08$, $p > .31$, $\eta_p^2 < .05$).

LPC Semantic Priming Effect on Day 2

Midline ANOVA. For the LPC window, the omnibus midline ANOVA revealed a Condition \times Relatedness [$F(1, 22) = 5.15$, $p = .03$, $\eta_p^2 = .19$] and Word-type \times Relatedness interaction effects [$F(1, 22) = 4.24$, $p = .05$, $\eta_p^2 = .16$]. To followup on the former interaction effect, one-way Relatedness ANOVAs were conducted separately for remote and recent words. It was found that the Relatedness effect emerged for remote words [$F(1, 22) = 18.09$, $p < .001$, $\eta_p^2 = .45$; $p_{\text{critical}} = .025$], but not for recent words [$F(1, 22) = 5.34$, $p = .031$, $\eta_p^2 = .20$; $p_{\text{critical}} = .025$]. To followup on the Word-type \times Relatedness interaction effect, one-way Relatedness ANOVAs were conducted separately for existing and novel words. For existing words (see Figure 3A), the Relatedness effect was significant [$F(1, 22) = 13.78$, $p = .001$, $\eta_p^2 = .39$; $p_{\text{critical}} = .025$]. For novel words (remote and recent; see Figure 4A), the Relatedness effect approached significance [$F(1, 22) = 5.02$, $p = .035$, $\eta_p^2 = .19$; $p_{\text{critical}} = .025$].

The critical comparison in the current study is whether the Relatedness effect differs for novel words tested immediately and 24 hours after learning, and thus planned tests were conducted to examine the main effect of Relatedness in the remote and recent conditions. Planned tests showed that novel words in the remote condition elicited the LPC semantic priming effect across all midline electrodes [$F(1, 22) = 10.54$, $p = .004$, $\eta_p^2 = .32$; see Figure 4A]. Importantly, this LPC semantic priming effect did not emerge for novel words in the recent condition [$F(1, 22) = 0.22$, $p = .65$, $\eta_p^2 = .01$].

Laterality ANOVA. The omnibus laterality ANOVA revealed a Word-type \times Relatedness interaction effect [$F(1, 22) = 4.36$, $p = .048$, $\eta_p^2 = .17$]. To followup on this interaction effect, one-way Relatedness ANOVAs were conducted separately for existing and for novel words. For existing words (see Figure 3A), the Relatedness effect emerged [$F(1, 22) = 15.09$, $p < .001$, $\eta_p^2 = .41$; $p_{\text{critical}} = .025$]. For novel words (see Figure 4A), the Relatedness effect approached significance [$F(1, 22) = 5.18$, $p = .033$, $\eta_p^2 = .19$; $p_{\text{critical}} = .025$].

Similar to the midline ANOVA, planned tests were conducted to examine the theoretically critical main effect of Relatedness in the remote and recent conditions separately. Planned tests showed a reliably LPC semantic priming effect for novel words in the remote condition [$F(1, 22) = 7.36, p = .01, \eta_p^2 = .25$]. Importantly, no LPC priming effect emerged for novel words in the recent condition [$F(1, 22) = 0.67, p = .42, \eta_p^2 = .03$].

Taken together, both N400 and LPC semantic priming effects were reliably observed for existing words, as expected. For novel words, a LPC but not an N400 semantic priming effect was obtained for novel words learned 24 hours before testing, suggesting that consolidation of novel words co-occurs with a more controlled process of semantic retrieval. No N400 or LPC effects were observed for novel words tested immediately after training. We will elaborate on these effects in the Discussion.

N400 Semantic Priming Effect on Day 8

Midline ANOVA. In the N400 window, the omnibus midline ANOVA revealed a Word-type \times Relatedness interaction effect [$F(1, 22) = 63.73, p < .001, \eta_p^2 = .75$]. Posthoc one-way Relatedness ANOVAs were conducted separately for existing and novel words. For existing words (see Figure 3B), the Relatedness effect emerged [$F(1, 21) = 75.40, p < .001, \eta_p^2 = .78; p_{\text{critical}} = .025$]. However, for novel words (see Figure 4B), the Relatedness effect was not significant [$F(1, 21) = 0.01, p = .99, \eta_p^2 < .001; p_{\text{critical}} = .025$].

Laterality ANOVA. The omnibus laterality ANOVA revealed a significant Word-type \times Laterality \times Relatedness effect [$F(1, 21) = 4.71, p = .04, \eta_p^2 = .18$]. Follow-up Laterality \times Relatedness ANOVAs were conducted separately for existing and novel words. For existing words (see Figure 3B), the Relatedness effect emerged [$F(1, 21) = 77.72, p < .001, \eta_p^2 = .79; p_{\text{critical}} = .025$]. In contrast, for novel words (see Figure 4B) no effects with the factor Relatedness effect emerged ($F_s < .282, p_s > .11, \eta_p^2 < .12; p_{\text{critical}} = .025$).

LPC Semantic Priming Effect on Day 8

Midline ANOVA. In the LPC window, the omnibus midline ANOVA revealed a significant Relatedness effect [$F(1, 21) = 24.10, p < .001, \eta_p^2 = .18$], indicating that both existing words and novel words reliably demonstrated the LPC semantic priming effect across the midline electrodes.

Laterality ANOVA. The omnibus laterality ANOVA revealed a Condition \times Laterality \times Relatedness interaction effect [$F(1, 21) = 6.29, p = .02, \eta_p^2 = .23$]. The absence of Word-type effects suggests that the LPC semantic priming effect was reliably observed for both existing and novel words tested on Day 8

(see Figures 3B and 4B, respectively). To followup on the three-way interaction effect, Laterality \times Relatedness ANOVAs were conducted separately for remote and recent words. For remote words, the Laterality \times Relatedness interaction effect emerged [$F(1, 21) = 6.65, p = .02, \eta_p^2 = .24; p_{\text{critical}} = .025$]. Further posthoc one-way Relatedness ANOVAs were conducted on the left and right hemisphere separately. It was found that the Relatedness effect was significant for both hemispheres, but was slightly stronger for the left [$F(1, 21) = 23.13, p < .001, \eta_p^2 = .52; p_{\text{critical}} = .013$] versus the right hemisphere [$F(1, 21) = 22.80, p < .001, \eta_p^2 = .52; p_{\text{critical}} = .013$]. For recent words, the main effect of Relatedness was significant [$F(1, 21) = 9.54, p = .006, \eta_p^2 = .31; p_{\text{critical}} = .025$] across lateral ROIs.

Taken together, as expected, existing words reliably elicited semantic priming effects in both the N400 and the LPC windows. For novel words, the absence of N400 semantic priming effects and the presence of LPC semantic priming effects on Day 8 (for words learned on Day 1 and on Day 2) indicates that after an extended period of offline consolidation, the semantic retrieval of novel words is not yet similar to that of existing words, for which robust N400 semantic priming effects were obtained.

Discussion

This study examined how monolingual English speakers with limited experience of learning foreign languages acquire novel word meanings, and how offline consolidation plays a role in the lexicalization process over shorter and longer periods of time. Besides widelyused behavioral measures, we recorded neural responses (ERPs) during online language processing to measure the emergence of lexicalization. Existing words showed a classic N400 followed by a LPC semantic priming effect, in all tests. Novel words elicited a LPC semantic priming effect (but no N400) after a 24-hour offline consolidation period, but no ERP effects immediately after learning. On Day 8, words trained on Day 1 and Day 2 showed LPC (but no N400) semantic priming effects. Behavioral measures showed high recognition accuracy for novel words 24 hours and 1 week after learning; semantic judgment scores were higher 24 hours after learning than immediately after learning (paralleling the ERP data). These results align with the CLS account of memory consolidation (e.g., Davis & Gaskell, 2009), proposing that after a period of offline consolidation novel words become integrated in the neocortical lexicon where lexical-semantic representations of novel words can interact with existing words during language use. In our study, offline consolidation led to increasingly word-like retrieval processes, but meaning retrieval of novel words 24 hours and one week after

learning is still more controlled (indexed by LPC effects on Day 2 and Day 8). This suggests that controlled meaning retrieval processes (rather than automatic retrieval as for existing words) enabled semantic priming after a 24-hour consolidation period, even when novel words are not yet fully lexicalized.

Is the trajectory of novel word learning and consolidation in monolingual learners without extensive prior experience in learning other languages different from the highly experienced foreign language learners as tested in Bakker et al. (2015)? Behavioral measures for novel words indicate that our inexperienced language learners performed slightly worse than Bakker et al.'s (2015) experienced language learners on semantic relatedness judgment (inexperienced, remote: 73%, recent: 67%; experienced, remote: 82%, recent: 86%; note that we did not directly compare the two learner groups, but that both learner groups were undergraduate students at a public university, and that their mean age and gender ratios were similar). This pattern aligns with behavioral research reporting that bilinguals/multilinguals show better learning and recall of novel vocabulary than monolinguals (e.g., Kaushanskaya, 2012; Kaushanskaya & Marian, 2009; Van Hell & Candia Mahn, 1997). For example, testing participants recruited from the same populations as in Bakker et al. (2015) and in the present study, van Hell and Mahn (1997) found that experienced language learners recall more novel (foreign) words directly after learning, and recall them faster, than inexperienced language learners.

The ERP data suggest that, at the neurocognitive level, encoding and consolidation of novel word meaning operates in a largely similar fashion for inexperienced (monolingual) and experienced (multilingual; Bakker et al., 2015) foreign language learners. Both types of learners showed a LPC semantic priming effect (indexing controlled semantic retrieval), but no N400 effect (indexing at least partial automatic semantic retrieval), after a 24-hour consolidation period. The main difference is that only the experienced learners (Bakker et al., 2015) also showed a frontal LPC priming effect shortly after learning (for words trained and tested on Day 2). The combined findings point at quantitative rather than qualitative differences in learning and consolidation trajectories of inexperienced and experienced foreign language learners: Word meaning lexicalization is a gradual process for both inexperienced and experienced learners, but prior language learning experience seems to expedite this process.

Davis and Gaskell's (2009) CLS account of word learning proposes two stages: a rapid, initial stage of encoding word information as an episodic memory trace supported by hippocampal and medial temporal learning, followed by postlearning offline consolidation during which memories about word

information achieve stable and long-term neocortical lexical representations. The findings of the present study and Bakker et al. (2015), combined with outcomes of related studies, suggest two further refinements of the original CLS account of word learning.

First, neocortical lexicalization is not necessarily a binary shift that occurs exclusively after a substantial postlearning delay: It can already be set in motion during or shortly after initial encoding. Specifically, although the inexperienced (monolingual) learners tested in the present study only showed a semantic priming effect when tested after 24 hours, the experienced (multilingual) learners in Bakker et al. (2015) showed priming effects (a frontal LPC effect) immediately after training. Learners' prior novel/foreign word learning experience, and the resulting knowledge of multiple languages, thus appears a factor that can expedite the lexicalization process, at least when novel word meanings are paired with novel meanings during encoding to examine the integration of novel word meanings with existing semantic knowledge (as in Bakker et al., 2015, and the present study). A possible reason for this difference may be related to a differential sensitivity to semantic information of multilingual and monolingual speakers, and its impact on the integration of novel word meanings. Specifically, Kaushanskaya and Rechtzigel (2012) examined whether bilinguals were more sensitive to semantic information associated with novel words than monolinguals, and manipulated the concreteness of the referent in a word-learning study. They found that concrete words were remembered better than abstract words, but more importantly, that this concreteness effect was larger in bilinguals than in monolinguals. Concreteness effects are generally taken to reflect richer semantic processing of concrete than abstract words, because concrete words have richer semantic networks than abstract words (e.g., de Groot, 1989) or entail both image and verbal representations (e.g., Paivio, 1986), and have more similar semantic representations across languages (van Hell & de Groot, 1998). Kaushanskaya and Rechtzigel (2012) argue that their observed larger concreteness effect in bilinguals reflects the bilinguals' higher sensitivity to semantic information during learning and higher levels of semantic activation in the bilingual than in the monolingual lexical-semantic system. The enhanced activation in the bilinguals' lexical-semantic system during the encoding of novel words and their meanings may benefit the formation of connections between neural representations of novel words and existing words in bilinguals relative to monolinguals. This would lead to faster and more successful lexicalization in bilinguals relative to monolinguals, and could explain why experienced (multilingual) learners tested by Bakker et al. (2015) showed a frontal LPC semantic priming effect immediately after learning, whereas

the inexperienced (monolingual) learners only show a LPC semantic priming effect after a 24-hour delay (even though both groups were exposed to the same encoding procedure). This account aligns with other factors or conditions that further the neural implementation of lexicalization during or shortly after initial encoding, such as the ease with which novel information can be assimilated to a prior schema (schema-consistent vs. schema-inconsistent information; cf. McClelland, 2013; Tse et al., 2007, 2011), fast-mapping paradigms (e.g., Coutanche & Thompson-Schill, 2014), or interleaving novel and existing neighbors during encoding (Lindsay & Gaskell, 2013; for more discussion, see McMurray, Kapnoula, & Gaskell, 2016; Takashima & Bakker, 2017).

Second, the present study suggests that postlearning lexical consolidation is a protracted and gradual process during which lexical retrieval gradually shifts from a more controlled to a more automatic process with newly learned words starting to behave like known words. Most previous studies that examined the CLS account measured lexical consolidation using fMRI or behavioral techniques. The present study (as well as Bakker et al., 2015) measured lexical consolidation using time-sensitive ERP methodology that allows for a more fine-grained assessment of how cognitive processes unfold over time. Both studies observed that existing words elicited robust N400 semantic priming effects, but novel words only elicited LPC priming effects 24 hours after learning. Moreover, the present study observed that one week after learning, novel words still elicited a LPC semantic priming effect, and not a word-like N400 semantic priming effect. Assuming that the N400 indexes more automatic aspects of semantic activation and the LPC indexes more strategic/explicit and controlled aspects of semantic retrieval (see Introduction), this finding suggests that postlearning lexicalization is not yet fully stabilized after a 24-hour or even a one-week period of offline consolidation. Rather, lexicalization of novel word meanings is a gradual and protracted process during which lexical-semantic retrieval gradually shifts from a more controlled to a more automatic process, and this gradual change seems to occur at a slower pace in inexperienced than in experienced learners.

Finally, we acknowledge several limitations of this study and avenues for further research. Full lexical integration of novel words requires linking multiple representations (orthography, phonology, meaning), and each mapping may be characterized by a different time course. Moreover, as alluded to above, the time course of consolidation is affected by different encoding strategies or specific demands of the word learning paradigms. This implies that consolidation patterns observed in the present study may play out differently for different novel stimuli or may change with other learning paradigms. For

example, under Nation's (2001) word learning framework, word knowledge can be divided into nine components (e.g., spoken form, grammatical functions, concepts, and referents), while the scope of the current study is limited to written form and meaning. Second, we closely followed the training and testing procedures of Bakker et al. (2015) and compared the outcomes of our inexperienced learners (on Day 2) with the outcomes of Bakker et al.'s experienced learners, but did not statistically compare our findings with those of Bakker et al. (2015). Finally, future work could take productive mastery of prior word knowledge into account (cf. Schmitt, 2019) or investigate the effect of existing vocabulary knowledge on overnight novel word integration (see James, Gaskell, Weighall, & Henderson, 2017, for a review).

Conclusion

In conclusion, while a semantic priming LPC effect for novel words emerged immediately after learning in experienced learners (Bakker et al., 2015), the inexperienced learners tested in this study demonstrated a LPC (but no N400) semantic priming effect only after a 24-hour, as well as after a one-week, offline consolidation period. These combined findings suggest that lexicalization of novel word meanings is a gradual and protracted process, and that this graduate change occurs at a slower pace in inexperienced than in experienced learners.

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Supporting Information

Additional Supporting Information may be found in the online version of this article at the publisher's website:

Appendix S1. Novel Words, Definitions, and Prime Words.

Appendix S2. Tables of Means and Standard Deviations for Performance on the Definition Recall Task, the 4AFC Word Recognition Task and the Semantic Relatedness Judgment Task.

Appendix S3. Behavioral ANOVA Results for the Definition Recall Task, the 4AFC Word Recognition Task and the Semantic Relatedness Judgment Task.

Appendix S4. ERP ANOVA Results for the Semantic Priming Task.

Appendix: Accessible Summary (also publicly available at <https://oasis-database.org>)

Brain Activity Reveals the Time-Course of Novel Word Meaning Acquisition in Inexperienced Learners

What This Research Was About and Why It Is Important

Prior research has found that when individuals learn new meaningful words, a period of offline consolidation (e.g., sleep) helps their brain associate new word meanings with the meanings of words they already know. Our study examined whether this consolidation effect would emerge in the case of monolingual speakers tested 1 day and 7 days after learning. We tested thirty undergraduate

students at a large public university, who were all native speakers of English and did not know a second language. The experiment comprised of three sessions: Day 1, Day 2, and Day 8. Participants learned the meanings of novel, made-up words on Day 1 and novel word meanings of another set on Day 2. On Day 2, we tested knowledge of meanings learned on that same day and Day 1, and on Day 8 we tested learning from Day 2, while participants' electrical brain activity was recorded. One day after learning, but not directly after learning, the monolinguals' brain made association between novel words and other common words they already knew. However, the novel word (e.g., *hodit*) meaning retrieval process was still more effortful than retrieving the meaning of words that were known for a long time (e.g., *paper*). This study shows that the learning and consolidation of novel word meanings is a gradual process. This process is affected by prior language learning experience, as novel word meaning consolidation was slower in the present inexperienced learners than in experienced, multilingual learners tested in an earlier study.

What the Researchers Did

- Thirty monolingual English students participated in the current study.
- Participants were trained to associate novel, made-up words (such as *hodit*) with brief definitions.
- They learned one set of novel words and had their knowledge of familiar words (e.g., *paper*) refreshed on Day 1, and they learned another set of novel words on Day 2.
- Participants' understanding of words from both sets was tested immediately after the learning on Day 2, and tested again on Day 8, but no learning took place on Day 8.
- Brain activity was recorded in each of the testing sessions on Day 2 and Day 8.

What the Researchers Found

- After one-night sleep, brain activity records showed that participants had successfully associated novel word meanings to that of existing related words, but this was not the case for novel words learned on the same day.
- A week later, brain activity measurements showed that the same participants had also managed to learn novel words from Day 2 and that they were still able to relate them to known concepts 7 days later.
- However, both at testing on Day 2 and Day 8, the associations between novel words and meaning were weaker than associations between already known words and their meaning, suggesting incomplete consolidation.

Things to Consider

- Considering that similar findings were obtained previously in experienced learners, the process of learning and remembering the meaning of novel words seems to be similar for monolingual and bilingual individuals.
- However, given that bilingual learners displayed immediate learning of novel words introduced on Day 2, our results indicate that learning novel words is faster when one has existing experience of word learning.

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