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How does the provision of semantic information influence the lexicalization of new spoken words?

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The integration of a novel spoken word with existing lexical items can proceed within 24 hours of learning its phonological form. However, previous studies have reported that lexical integration of new spoken words can be delayed if semantic information is provided during learning. One possibility is that this delay in lexical integration reflects reduced phonological processing during learning as a consequence of the need to learn the semantic associations. In the current study, adult participants learnt novel words via a phoneme monitoring task, in which half of the words were associated with a picture referent, and half were phonological forms only. Critically, participants were instructed to learn the forms of the novel words, with no explicit goal to learn the word–picture mappings. Results revealed significant lexical competition effects emerging one week after consolidation, which were equivalent for the picture-present and form-only conditions. Tests of declarative memory and shadowing showed equivalent performance for picture-present and form-only words, despite participants showing good knowledge of the picture associations immediately after learning. These data support the contention that provided phonological information is recruited sufficiently well during learning, the provision of semantic information does not slow the time-course of lexical integration.

Keywords: Lexicalization; Word learning; Semantics; Memory consolidation.

An important aspect of acquiring new memories is their integration with existing knowledge. One domain investigating the integration of new with old memories is word learning. A body of evidence now suggests that new words can be explicitly recognized immediately after learning, but that a slower process of offline memory consolidation is required for new words to be integrated with existing lexical items (e.g., Dumay & Gaskell, 2007, 2012; Tamminen, Payne, Stickgold, Wamsley, & Gaskell, 2010). A central question is thus what factors govern the time-course and success of this integration process. The majority of investigations of lexical integration have focused on novel spoken words acquired with phonological information alone; these studies have typically revealed lexicalization of novel words within a 24-hour time window after learning (e.g., Bakker, Takashima, van Hell, Janzen, & McQueen, 2014; Brown, Weighall, Henderson, & Gaskell, 2012; Davis, Di Betta, Macdonald, & Gaskell, 2009; Dumay & Gaskell, 2007, 2012; Henderson, Weighall,

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Brown, & Gaskell, 2012, 2013). The time-course of lexical integration for novel words acquired with semantic information has remained comparatively underexplored; however, those studies that have examined this report that semantic exposure during training can delay this time-course (Dumay, Gaskell, & Feng, 2004; Takashima, Bakker, van Hell, Janzen, & McQueen, 2014; cf. Coutanche & Thompson-Schill, 2014). The current study addresses whether the type of encoding that novel words undergo during learning influences the time-course and success of lexical integration.

Lexical competition is a central feature of spoken word recognition (e.g., Marslen-Wilson, 1987) and in recent years has been used to measure lexical integration of newly learned spoken words (e.g., Gaskell & Dumay, 2003). The central finding in this body of literature is that recognition of an existing spoken word (e.g., cathedral) is slowed as a result of an individual's learning of an onset-related novel word (e.g., cathedruke; Gaskell & Dumay, 2003). Research shows that the engagement of novel words in lexical competition often requires a period of overnight (sleep-related) consolidation (Dumay & Gaskell, 2007; also Bakker et al., 2014; Davis et al., 2009; Dumay & Gaskell, 2012; Henderson, Weighall, et al., 2013; Tamminen et al., 2010; Takashima et al., 2014). These results have been obtained from training on the phonological forms of novel spoken words in the absence of any semantic information. It is thus evident that semantic information is not required for lexicalization to emerge following overnight consolidation.

Strikingly, however, the provision of semantic information during training appears to delay the time-course of lexical integration relative to phonological training alone. A handful of previous studies have specifically addressed the role of meaning in the lexicalization of new spoken words. Dumay et al. (2004) assessed whether the offline consolidation period required for lexicalization was the result of impoverished training conditions, which lacked meaning. Participants learnt novel words via phonological training, or embedded in sentential contexts through which a meaning could be acquired. After 24 hours, only the words learnt from phonological training, with no associated meaning, showed evidence of lexical competition. It was only after one week that the words learnt with a meaning entered into lexical competition. Takashima et al. (2014) obtained a similar result, in which participants learnt novel words with or without picture referents via phonological training. Only the words trained in the absence of a picture referent showed evidence of lexical competition after 24 hours. The results of Dumay et al. (2004) and Takashima et al. (2014) are thus consistent in suggesting that semantic exposure can delay the time-course of lexicalization relative to phonological exposure alone.

A theoretical account of the gradual integration of new with existing lexical items comes from the complementary learning systems (CLS) model (Davis & Gaskell, 2009; McClelland, McNaughton, & O'Reilly, 1995). The CLS model is a dual-systems account of memory, which proposes that word learning is mediated by two distinct learning systems: the fast-learning hippocampal system, which enables access to explicit knowledge about new words immediately, and the slower neocortical system representing longer term, integrated memories. Critically, the rate of neocortical learning is slow to avoid new neocortical mappings damaging existing knowledge (French, 1999). McClelland (2013) recently proposed that the rate of neocortical learning is contingent on prior knowledge, whereby the integration of new memories into dense existing networks may necessitate a more gradual consolidation time-course, due to a higher likelihood of interference than that for the integration of memories into sparser networks, with less existing knowledge for interference (see also Tamminen, Lambon Ralph, & Lewis, 2013). One possibility from this proposal is that semantically associated words may necessitate a more gradual rate of integration due to the additional semantic information posing a greater potential for interference with existing lexical items.

However, an alternative possibility is that the slower entry of semantically associated novel words into lexical competition arises because the provision of semantic information pulls the attentional focus away from phonological information during learning. Such a proposal is generally consistent with the emerging view that the nature of encoding can influence the time-course of lexical integration (Coutanche & Thompson-Schill, 2014; Fernandes, Kolinsky, & Ventura, 2009; Szmalec, Page, & Duyck, 2012). Why would the robust encoding of phonological information be potentially critical for lexical integration of new spoken words? A key reason that the strength of phonological encoding could influence lexicalization is that spoken word recognition is online and incremental, and robust phonological representations may be particularly able to engage in competition with neighbouring items (e.g., McClelland & Elman, 1986). The association between immediate serial recall and phonological form learning (e.g., Baddeley, Gathercole, & Papagno, 1998; Gupta, 2003; Page & Norris, 2009; Papagno & Vallar, 1992) further supports the contribution of the ordered retention of phoneme sequences to successful spoken word learning. Further, well-specified phonological representations may be more readily linked to the phonological forms of existing lexical items, and these links could be particularly important for testing lexical competition in spoken word recognition. In the CLS account, the integration of new and existing knowledge is governed by the reinstatement of hippocampal memories, which are linked with existing knowledge in the neocortex. One possibility is that weaker phonological representations of new words in the hippocampus form more fragile links with the phonological forms of existing words in the neocortex. This would result in weaker reinstatement of these links during offline consolidation, resulting in a slower integration of new words with phonologically similar lexical items.

It follows that task instructions biasing attentional focus away from phonological encoding may result in a slower lexicalization time-course. In both Dumay et al. (2004) and Takashima et al. (2014), participants were instructed to learn the novel meanings of the semantically associated words, thus possibly reducing the recruitment of phonological information during learning. Attentional focus from task instructions can enhance processing of specific psycholinguistic attributes; for example, Yoncheva, Blau, Maurer, and McCandliss (2010) instructed participants to attend to either grapheme–phoneme correspondences or whole-word forms when learning to read novel words written in an artificial script, and observed that expertise for orthographic decoding emerged only for participants trained on grapheme–phoneme correspondences. Ruz and Nobre (2008) similarly observed heightened event-related potential (ERP) responses for orthographic, phonological, and semantic attributes of existing words when participants were cued to attend to these attributes on a trial-by-trial basis. Consistent with these reports, it is therefore possible that the goal of acquiring novel word–meaning mappings enhances the processing of semantic attributes of novel words, reducing phonological recruitment during training.

The current study therefore reexamined the impact of semantic information on the lexicalization time-course of novel words in adults, by equating the task goals for learning new spoken words with and without semantic information. To achieve this, the current study extended the methodology used by Takashima et al. (2014) by training participants on new words with or without an associated referent in a phonological training task, but critically altered the task instructions to equate attention to phonology for both novel word types. We trained participants on novel words with an associated picture referent (picture present) and without an associated referent (form only) in a phoneme monitoring task, in which participants monitored novel spoken words for target phonemes. Participants were instructed to learn the word forms, with no goal of learning the word–picture associations; therefore, both novel word categories were acquired with a focus on only phonological encoding. Following the phoneme monitoring training, tests of lexicalization (pause detection), shadowing, recognition memory, free recall, and picture association memory were administered immediately after learning, after 24 hours of consolidation, and after one week of consolidation. It was predicted that if slower lexicalization for semantically associated words in previous investigations (Dumay et al., 2004; Takashima et al., 2014) were due to semantic training drawing attentional focus away from phonology during training, lexical competition effects in the current study would show an equivalent time-course for novel words acquired both with and without a semantic referent.

Method

Participants

Thirty participants were recruited from Royal Holloway, University of London. Participants were native English speakers, with a mean age of 20.93 years ($SD = 3.53$, range = 18–37, 6 males). None of the participants reported language or reading impairments. Participants were paid £25 as compensation for their participation upon completion of all three sessions.

Materials

Spoken stimuli. The word stimuli consisted of 160 triplets consisting of a bi- or trisyllabic monomorphemic existing base word (e.g., cathedral) and two novel words that diverged from the base word at the final vowel (e.g., cathedruke, cathedruce). Participants learned one novel item from each triplet during training. The corresponding existing base word was used to test lexical competition effects in the pause detection task, and the other novel item was used as a foil during the recognition memory task. Sixty-four of the triplets were from Tamminen and Gaskell (2008), and 96 triplets were selected from the stimulus set of Gagnepain, Henson, and Davis (2012). The base words were between 4 and 11 phonemes in length ($M = 6.81$, $SD = 1.14$) and had a log CELEX total frequency between 0 and 1.7 occurrences per million ($M = 0.61$, $SD = 0.35$; Baayen, Piepenbrock, & van Rijn, 1993). The uniqueness point of the base words, the phoneme where the base word diverged from all existing cohort neighbours, varied between the second and ninth phonemic position ($M = 4.36$, $SD = 1.18$). All 160 triplets were randomly divided into five lists of 32 items each, which did not significantly differ on the log frequency of the base word, the number of syllables, the number of phonemes, and the phonemic position of the uniqueness point (all $F\text{s} < 1.1$, $p\text{s} > .3$). A different set of untrained control words was used on each day of testing in the shadowing and pause detection tasks, and as such the five item lists were counterbalanced between each cell of the design: picture present, form only, untrained control Day 1, untrained control Day 2, and untrained control Day 8. For the pause detection task, an additional 288 words were chosen as filler items. All fillers were monosyllabic ($N = 59$), disyllabic ($N = 125$), or trisyllabic ($N = 104$) monomorphemic known words, with an average phoneme length of 5.64 ($SD = 1.40$) and log frequency of 0.83 ($SD = 0.42$). All items were recorded with a monoaural recording at 22 Hz, by a native Southern British English female speaker, and were edited in CoolEdit 2000 to equate amplitude across items.

Picture stimuli. The referents for the picture-present words consisted of 32 pictures of obscure objects. Thirty of the chosen pictures were obscure items without a clear label selected via a Google image search, and two were from the NOUN (Novel Object and Unusual Name) database (Horst & Hout, 2014). The pictures were presented in colour on a black background and were 500 × 500 pixels in size. Each participant was allocated a different word–picture mapping for the picture-present training condition. Spoken stimuli lists and picture referents are available as Supplemental Material.

Design and procedure

Experimental procedure. The phoneme monitoring and association memory tasks were run in E-Prime 2.0, and the pause detection, shadowing, and recognition memory tasks were run in DMDX (Forster & Forster, 2003). After the training session (Day 1) participants returned at the same time the following day for a second test session 24 hours after learning (Day 2) and again one week after the training session (Day 8). Participants were scheduled at similar times of day for the three sessions (in the morning, early afternoon, or late afternoon) to minimize circadian differences between each test session. A schematic of the experiment can be seen in Figure 1.

Phoneme monitoring training. On Day 1, participants were trained on the 64 novel words in the phoneme monitoring task, where 32 of the novel words were presented as phonological forms in isolation (form only), and 32 were presented with an associated picture referent on the screen (picture present). The task instructions stated:

> This is a task for learning new words, and your goal is to memorise as many of the new words as you can. In this task you will hear some new words, and your aim is to listen for a target sound in these new words. Sometimes a picture may appear with a word. These pictures may help you, but remember your main goal is always to learn the new words and memorise as many as you can.

Importantly, these instructions emphasized the learning of the novel phonological forms as the task goal, with no goal of learning the word–picture associations.

The phoneme monitoring task consisted of 36 blocks, with each novel word presented once per block in a randomized order. In each block, participants listened for the presence or absence of one of six target phonemes (/k, n, t, m, l, s/). Each phoneme was monitored for six times in that fixed order. The phonemes were chosen such that they appeared in all positions across the words, with rates of occurrence as similar as possible across the five word lists. The mean rate of target occurrence across lists was 34% ($SD = 9$). At the start of each block the target phoneme was presented on the screen, with a written example (e.g., "Listen for /k/, as in 'book'"), and participants then heard two repetitions of the target phoneme via headphones before beginning the task. During the task, participants heard each word via headphones and responded "yes" via a button box if they heard the target sound or "no" if they did not hear the target sound. For the picture-present words the picture appeared in the centre of the screen at the same time as the onset of the spoken word, to prevent participants predicting word identity on the basis of the picture, and stayed on screen for 1000 ms after the offset of the word. A fixation cross was presented in the centre of the screen during form-only trials. Participants had 3000 ms after the onset of the word to make a response, and the intertrial interval was 700 ms. Every quarter of the task, a break screen informed participants how far they had progressed through the training, and they were encouraged to take a break to maintain motivation and attentiveness.

Lexicalization test: Pause detection. In the pause detection task, participants were required to detect the presence or absence of a 200-ms pause (Mattys & Clark, 2002) in the 96 experimental base words and 288 fillers, presented in a randomized order. Participants were instructed that they would hear a word via the headphones and to press the "yes" button if a pause was present and the "no" button if a pause was absent. For the existing base words (e.g., cathedral) in the pause detection task, the 200-ms pause was inserted at the uniqueness point using the same procedure as that of Gaskell and Dumay (2003). The filler words had 200-ms pauses inserted towards the beginning, middle, or end of the word with equal frequency to encourage participants to attend to the whole item. In the task, each trial began with a 250-ms fixation cross before the onset of the word. Participants had 3000 ms to respond following the onset of the word, with an intertrial interval of 1000 ms. During the task there was a break every 100 trials, and no feedback was given.

Shadowing. Participants heard the 64 novel words and 32 untrained novel words via headphones, presented in a randomized order. Participants were instructed to repeat the word aloud as quickly and accurately as they could. Each trial started with the 250-ms presentation of a fixation cross, and participants had 3000 ms to respond. Responses were recorded via a Beyerdynamic microphone.

Free recall. In the free recall task, participants were given 3 minutes to verbally recall as many of the trained novel words as they could remember from the training session. The instructions specified that participants should try to remember the words from the learning task that they completed, to prevent participants recalling items from the

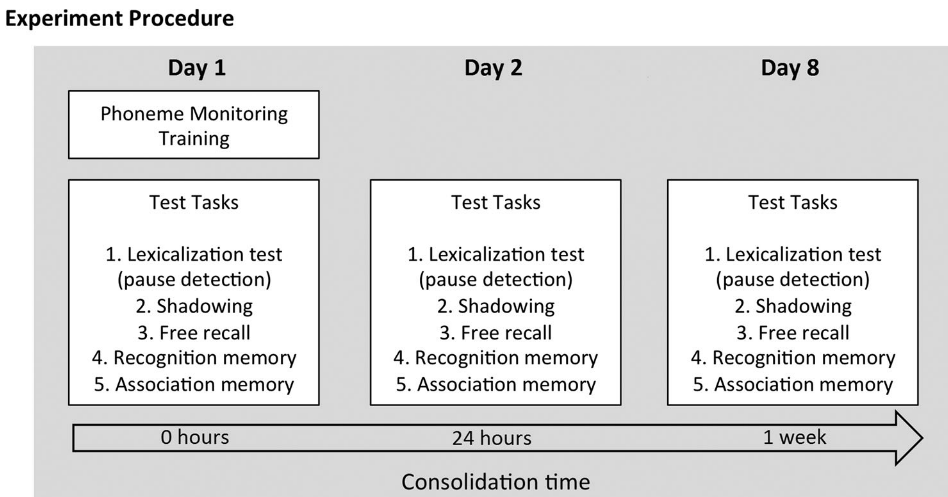

Figure 1. *Schematic of the experimental design.*

pause detection or shadowing tasks. Responses were recorded in Audacity.

Recognition memory. The recognition memory test presented participants with the 64 trained novel words (e.g., cathedruke) and 64 untrained foils (e.g., cathedruce). Participants heard each word via headphones, and their task was to respond whether the word was one they learnt during the phoneme monitoring task or was an untrained novel word. Each trial began with a 500-ms fixation cross before the onset of the word, to which participants had 3000 ms to respond. Trials were presented in a pseudorandomized order, with at least four items between a novel word and its foil (Tamminen et al., 2010). A different pseudorandomized order was used for each participant on each day of testing.

Association memory. The association memory task tested participants' recall of the picture associations for the picture-present words and memory of no association for the form-only words. The 64 trained novel words were presented via headphones, with three response options presented on the screen: two pictures from the phoneme monitoring task, and an option of "none". For the picture-present words, one picture was always the correct referent for that word, and one picture was the referent for another word from the training task. In the case of the form-only words, both pictures were associated with two of the picture-present words from the training task. The incorrect pictures presented with each word remained the same across each day of testing, to prevent participants from learning associations by co-occurrences between the picture-present novel words and their correct referent across the testing days. The location of the two pictures and "none" option on the screen (i.e., left, right, middle) was different for each word on each day of testing. The instructions stated that participants' task was to remember which words and pictures went together from the training task and to select "none" if they thought the word did not have an associated picture. Participants responded via keyboard to indicate their choice, and there was no time limit on responses.

Results

Reaction time and accuracy data were analysed using by-subject (F_1) analyses of variance (ANOVAs), and by-item (F_2) ANOVAs for the test tasks. Greenhouse–Geisser corrected F-statistics, degrees of freedom, and p-values are reported where assumptions of sphericity were violated. In all ANOVAs, item list was included to reduce the estimate of random variance (Pollatsek & Well, 1995). Main effects or interactions with this variable are not reported. Reaction-time analyses were conducted on log-transformed data to satisfy the assumption of normality and to reduce the effect of outliers (Ulrich & Miller, 1994). Retransformed data are presented in tables and figures for ease of interpretation. Error bars represent standard error for the participant-averaged means, corrected for within-participant contrasts where appropriate (Cousineau, 2005).

Association memory

The association memory test assessed participants' learning of the picture referent for the picture-present words. Because three response categories were present in the task (either picture or "none"), accuracy was scored using the percentage of correct responses for each novel word type (rather than d'), and percentages were arcsine-transformed for analysis to better meet the assumption of normality for percentage/proportion data. Trials faster than 300 ms were excluded (0.31%).

Table 1 presents the percentage accuracy scores for the picture-present words across the three response categories of correctly selecting the target (referent) picture, selecting the incorrect foil picture, or selecting "none" to indicate no associated picture. A repeated measures ANOVA on target hits with the factor of day of testing (Day 1, Day 2, Day 8) yielded a significant main effect of day, $F_1(2, 50) = 18.86$, $p < .001$, in which target hits decreased over each day of testing [Day 1–Day 2: $t_1(29) = 4.14$, $p < .001$; Day 2–Day 8: $t_1(29) = 2.71$, $p < .05$]. Target hits remained significantly above chance on each day of testing, however [Day 1: $t_1(29) = 7.96$, $p < .001$; Day 2: $t_1(29) = 6.16$, $p < .001$; Day 8: $t_1(29) = 4.72$, $p < .001$]. Association memory performance thus indicated that participants learnt the word–picture mappings for the picture-present words during training and retained knowledge of these associations on each day of testing.

Table 1. *Percentage of responses in each response category for the picture-present words in the association memory task?*

Response	*Day 1*	*Day 2*	*Day 8*
Target picture	69.69 (21.87)	61.25 (23.29)	54.17 (22.48)
Foil picture	6.13 (8.06)	5.67 (11.40)	6.48 (9.96)
"None"	25.58 (20.38)	34.84 (22.04)	39.70 (24.54)

Note: The percentages are the raw untransformed percentages, with standard deviation shown in parentheses.

Phoneme monitoring

Twenty-five participants were included in the phoneme monitoring analysis, due to a programme error failing to save the output file for five participants. For the accuracy and reaction time analysis, the 36 exposures to each novel word over the course of the phoneme monitoring task were divided into six blocks of six exposures each.

Accuracy. The overall error rate in the phoneme monitoring task was 14.23% ($SD = 6.14$), and performance was thus significantly above chance levels, $t_1(24) = 16.09$, $p < .001$. A repeated measures ANOVA on percentage accuracy, with the within-subjects factor of condition (picture present, form only) and block (1–6), revealed no significant main effects of condition or block, or

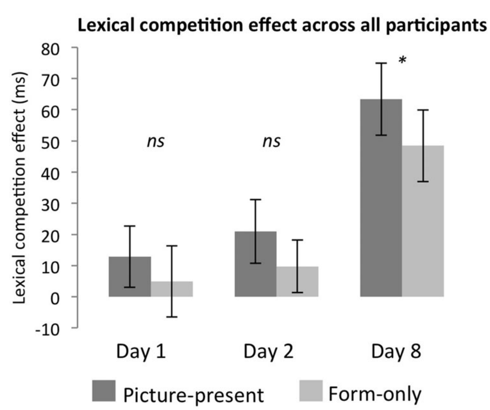

Figure 2. *The lexical competition effect immediately, 24 hours, and one week after training. The lexical competition effect is averaged over all data points for participants and items. The error bars show the standard error of the mean corrected for within-subjects comparisons.* Note: *The asterisk indicates a significant lexical competition effect.*

any interaction between these factors (all *F*s < 1, *p*s > .5). There was thus no significant difference between the picture-present and form-only words in terms of accuracy.

Reaction times. A repeated measures condition by block ANOVA was run on reaction times from correct trials only (85.77% of trials). This yielded a significant main effect of block only, $F_1(5, 100) = 5.51$, $p < .005$, in which responses sped up significantly between the first and final block of training, $t_1(24) = 3.01$, $p < .05$ (Block 1: *M* = 1160 ms, *SD* = 124; Block 6: *M* = 1082, *SD* = 128). The main effect of condition was not significant, $F_1(1, 20) = 0.23$, $p = .64$, and the Condition × Block interaction did not reach significance, $F_1(5, 100) = 2.14$, $p = .067$. Whilst this interaction was marginal, and possibly underpowered due to the absence of five participants, the lack of a main effect of condition, in contrast to Takashima et al. (2014), suggested that the speed of target detection did not robustly differ between the two training conditions.

Pause detection test

The pause detection data from all 30 participants were included in the analysis. No participants were excessively slow (with reaction times > 2.5 *SD*s from the group-level condition mean) or error prone (>50% errors in one or more conditions), and all were therefore retained. Incorrect trials were excluded (5.13% of trials), and data were trimmed for reaction times faster than 200 ms and slower than 2.5 standard deviations from each participant's conditional mean (on the basis of both pause-present and pause-absent trials), which excluded 3.02% of trials.

The effect of lexical competition was measured as slower reaction times to experimental base words for which a potential new competitor had been acquired during training than to control base words for which no new competitor had been learnt. The emergence of a lexical competition effect was first tested by comparing response times to experimental base words (both picture-present and form-only words) to control base words. Reaction times were submitted to a repeated measures ANOVA with the effects of competition (experimental versus control base word), day of testing (Day 1, Day 2, Day 8), and pause presence (pause present, pause absent). Only the effects of competition and interactions with competition are reported. This analysis yielded a significant Competition × Day interaction [$F_1(2, 50) = 4.39$, $p < .05$; $F_2(2, 306) = 3.33$, $p < .05$]. Follow-up paired *t* tests indicated that the effect of competition was present on Day 8 of testing only, with slower responses to the experimental base words than to the control base words [Day 1 and Day 2: *t*s < 0.8, *p*s > .4; Day 8: $t_1(29) = 3.10$, $p < .01$; $t_2(159) = 4.92$, $p < .001$] (see Figure 2).

Due to a lexical competition effect emerging on Day 8 of testing, indicated by significantly slower responses to experimental base words than to controls, a second analysis then examined whether this lexical competition effect differed between the picture-present and form-only condition base words. The effect of training condition on the time-course of this lexical competition effect was tested by submitting the magnitude of the lexical competition effect, the difference between experimental and control base word reaction times in each condition, to an ANOVA with the factors of condition (picture present versus form only), day (Day 1, Day 2, Day 8), and pause presence (pause present, pause absent). This yielded no interaction between condition and day (F_1 and F_2 both < 1, *p*s > .6). Only a main effect of day was present [$F_1(2, 50) = 4.52$, $p < .05$; $F_2(2, 308) = 13.10$, $p < .001$], whereby the lexical competition effect was larger on Day 8 of testing than on Day 2 [$t_1(29) = -2.61$, $p < .05$; $t_2(159) = -2.86$, $p < .01$], but did not differ between Day 2 and Day 1 of testing (both *t*s < .5, *p*s > .8). The pause detection analyses thus indicated that a significant lexical competition effect emerged on Day 8 of testing only and was equivalent for both form-only and picture-present base words.

Recognition memory and lexical competition. In contrast to lexical competition emerging on Day 8 for both conditions in the current study, lexical competition effects were present on Day 2 in Takashima et al. (2014; for form-only words only). One possibility for this discrepancy was due to weaker initial encoding of the novel words in the current study due to learning 64 items on Day 1, compared to only 40 items in Takashima et al. (2014). Sixty-four items were trained in the current study to avoid a loss of power resulting from using 20 items per cell of the design (as the majority of lexicalization studies have used 24–36 items per cell; e.g., Dumay & Gaskell, 2007, 2012). However, weaker episodic representations resulting from the larger number of items to be learned on Day 1 could have prolonged the lexicalization time-course. A second analysis therefore addressed whether participants with greater recognition memory of the novel words on Day 1 (immediately after learning, indicating stronger encoding) would subsequently show lexical competition on Day 2.

A median split was conducted on participants' average recognition memory accuracy (measured by d') on Day 1. This yielded a low recognition group with a mean d' of 1.00 ($SD = 0.37$) and a high recognition group with a mean d' of 2.22 ($SD = 0.72$; median = 1.44). Participants' lexical competition effect in each condition was submitted to a mixed ANOVA with within-subjects factors of condition (picture present, form only) and day (Day 1, Day 2, Day 8), with recognition group (low, high) as a between-subjects factor. This yielded a significant within-subjects effect of day, $F_1(2, 40) = 3.6$, $p < .05$, which was qualified by a Condition × Day × Recognition Group interaction, $F_1(2, 40) = 4.87$, $p < .05$. The between-subjects main effect of recognition group did not reach significance, $F_1 = 3.01$, $p = .1$, and all other within-subjects main effects and their interactions were not significant, $F\text{s} < 1.1$, $p\text{s} > .4$.[1]

The three-way interaction indicated that the effect of condition and day on lexicalization differed between the recognition memory groups, suggesting that memory strength influenced the emergence of lexicalization. To verify this, the three-way interaction was followed up by separate Condition (2) × Day (3) mixed ANOVAs on each recognition group separately. In the high recognition group this yielded a significant main effect of day, $F_1(2, 20) = 5.31$, $p < .05$ (all other $F\text{s} < 2.02$, $p\text{s} > .16$). Planned comparisons revealed a significant increase in lexical competition between Day 2 and Day 8 only, $t_1(14) = -3.14$, $p < .01$ (Day 1 to Day 2: $t < 1$, $p > .7$). Reaction times to the experimental base words were slower than the control base word responses on Day 8 of testing only [Day 8: $t_1(14) = 3.62$, $p < .01$; Day 1 and Day 2: $t\text{s} = 1$, $p\text{s} > .3$]. Participants with high recognition memory therefore showed lexical competition on Day 8 of testing, with no lexicalization on Day 2.

In contrast to the high recognition group, the low recognition group showed no main effect of day, $F_1(2, 20) = 0.58$, $p = .57$, with only a trend-level Condition × Day interaction, $F_1(2, 20) = 2.91$, $p = .08$. It was therefore the case that only the high recognition memory participants showed a statistically significant increase in the lexical competition effect after one week of consolidation. These findings thus indicated that whilst memory strength constrained subsequent lexicalization, it did not contribute to a lexicalization effect on Day 2 of testing (Figure 3).

Contributions to lexicalization on Day 8

Given the equivalent time course of lexicalization for picture-present and form-only words in the current study, compared to previous reports of semantically associated words showing a delayed time-course relative to those acquired as phonological forms only (Dumay et al., 2004; Takashima et al., 2014; cf. Henderson, Weighall, & Gaskell, 2013), correlational analyses aimed to determine the contribution of phonological processing during training to lexicalization after one week. The first correlational analysis looked for a relationship between phoneme monitoring accuracy during training, as an index of participants' engagement with the phonological forms of the novel words during acquisition, and the magnitude of the lexical competition effect on Day 8. Given that only participants high in recognition memory after training showed a significant lexical competition effect after one week, a second correlation

[1]The exception to this was the within-subjects main effect of condition, which showed trend-level significance, $F(1, 20) = 3.36$, $p = .082$.

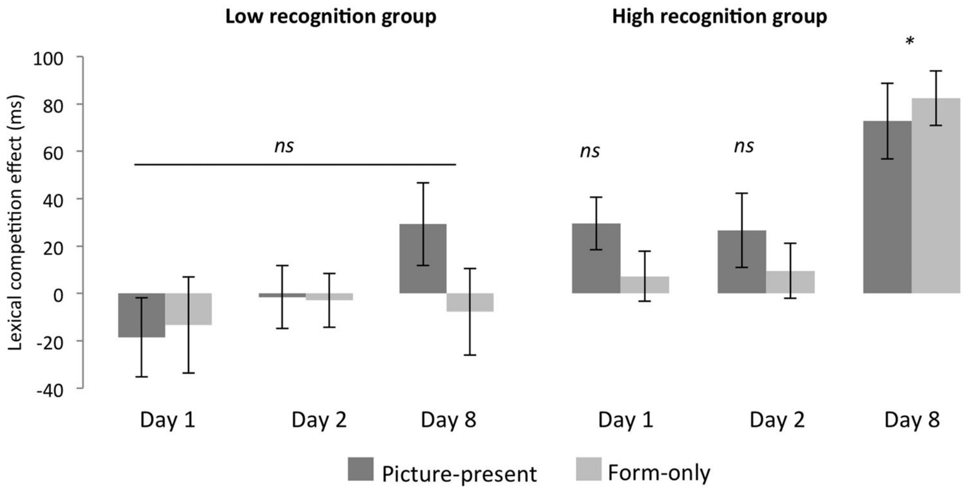

Figure 3. *The lexical competition effect, split by recognition memory group. The error bars show standard error of the mean corrected for within-subjects comparisons.*
Note: *The asterisk indicates a significant lexical competition effect.*

analysis further assessed whether the strength of recognition memory on Day 1 was supported by phoneme monitoring accuracy during training and thus subsequently supported lexicalization.

Data from one participant were removed from these analyses due to the participant having a lexical competition effect and a d' score > 2.5 standard deviations from participants' mean and being a clear outlier on the scatterplots. All correlations were bivariate, and each measure was averaged across both picture-present and form-only words due to no effect of training on phoneme monitoring accuracy, recognition accuracy, or lexical competition being present in the main analyses. The first correlation analysis indicated that the contribution of phoneme monitoring accuracy to lexical competition on Day 8 was not significant, $r(24) = .25$, $p = .25$. However, the second correlation analysis indicated that phoneme monitoring accuracy was positively correlated with recognition memory immediately after learning, whereby participants with greater phoneme monitoring accuracy during the training task showed greater recognition memory accuracy in the Day 1 test, $r(24) = .67$, $p < .001$. Because the second correlation suggested that higher phoneme monitoring accuracy was tied to stronger recognition memory immediately after learning, it was assessed whether recognition memory subsequently contributed to lexicalization after one week (as suggested by the median split analyses). Recognition memory accuracy on Day 1 was indeed positively correlated with the magnitude of the lexical competition effect on Day 8, $r(29) = .37$, $p < .05$. These correlational analyses thus suggested that stronger recognition memory immediately after learning was tied to higher phoneme monitoring accuracy, and stronger recognition memory subsequently supported lexicalization after one week of consolidation. Figure 4 presents scatterplots of these correlations.

Shadowing

The onset of shadowing responses were marked using Check Vocal (Protopapas, 2007), using the criteria for marking speech onsets described by Rastle, Croot, Harrington, and Coltheart (2005). Reaction times were measured from the onset of the to-be-repeated word to the onset of participants' response. Erroneous responses were marked from omissions (i.e., trials with no response) and

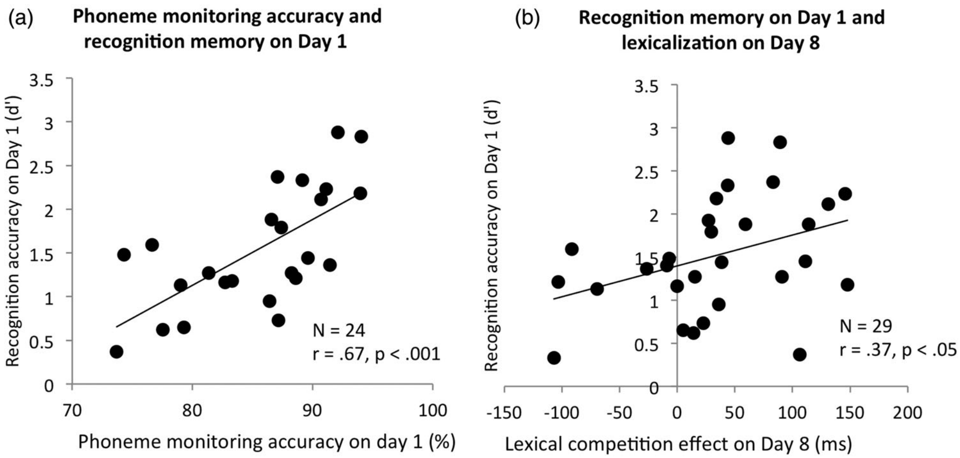

Figure 4. *Relationship between phoneme monitoring, recognition memory, and lexicalization. (a) The relationship between phoneme monitoring accuracy and recognition memory at the immediate test, and (b) the relationship between recognition memory at the immediate test and the magnitude of the lexical competition effect after one week of consolidation. Each data point is a participant's average score across both form-only and picture-present words.*

incorrect productions, in which participants often replaced a syllable towards the end of the target word with another syllable (e.g., saying albatran instead of the correct albatrum). Erroneous trials were rare (0.32%) and were excluded from the shadowing analysis. Responses faster than 300 ms were additionally excluded (0.13%), and no responses were slower than 2500 ms.

Shadowing reaction times were submitted to by-participants and by-items ANOVAs with the factors of training (trained versus untrained) and day of testing (Day 1, Day 2, Day 8). This analysis yielded a significant main effect of training [$F_1(1, 25) = 83.41$, $p < .001$; $F_2(1, 155) = 217.66$, $p < .001$], and day [$F_1(2, 50) = 4.90$, $p = .01$; $F_2(2, 310) = 119.94$, $p < .001$], with no interaction (Fs < 2, ps $> .1$). Responses to picture-present and form-only trained items were thus faster than those to untrained items across each day of testing (see Table 2). Follow-up comparisons on the main effect of day indicated that responses to all items sped up between Day 1 and Day 2 of testing [$t_1(29) = 2.45$, $p < .05$; $t_2(159) = 7.9$, $p < .001$], but not between Day 2 and Day 8 [significant by items only; $t_1(29) = 0.92$, $p = .37$; $t_2(159) = 2.60$, $p = .01$].

As the shadowing of trained items was thus faster than that of untrained items overall, a second analysis examined whether the magnitude of the training effect (the reaction time, RT,

Table 2. *Shadowing reaction times*

	Day 1 test		*Day 2 test*		*Day 8 test*	
Condition	*RT ms*	*Training effect*	*RT ms*	*Training effect*	*RT ms*	*Training effect*
Picture present	1097 (174)	31 (27)	1057 (150)	38 (38)	1045 (160)	42 (33)
Form only	1094 (176)	34 (30)	1058 (155)	37 (25)	1047 (157)	40 (26)
Untrained	1128 (176)		1096 (153)		1087 (163)	

Note: The training effect is the trained novel word shadowing reaction time (RT; in ms from word onset) subtracted from the untrained novel word shadowing RT, for each training condition on each day of testing. A positive training effect thus indicates faster shadowing latencies for trained words than for untrained words. The standard deviation is that of the effect across participants. Standard deviations are in parentheses.

difference between trained items and untrained items) differed for picture-present and form-only words. The training effect was submitted to an ANOVA with the factors of condition (picture present, form only) and day (Day 1, Day 2, Day 8). This yielded no significant main effect of condition or day, or interaction (all Fs < 2, ps > .2). The shadowing analyses thus indicated that speeded access to the trained picture-associated and form-only words was faster than that to untrained items on each day of testing, but that the magnitude of this effect was unaffected by training condition or day of testing.

Free recall

The free recall data were analysed by calculating the percentage of total words recalled correctly. These percentages were arcsine-transformed to better meet the assumption of normality for percentage/proportion data and were submitted to separate by-participants (F_1) and by-items (F_2) ANOVAs (as in e.g., Dumay & Gaskell, 2012; Henderson, Powell, Gaskell, & Norbury, 2014; Henderson, Weighall, et al., 2013; Tamminen et al., 2013; Tamminen et al., 2010). Both ANOVAs included the within-subject factors of condition (picture present, form only) and day of testing (Day 1, Day 2, Day 8). A significant main effect of day was present [$F_1(2, 50) = 91.66$, $p < .001$; $F_2(2, 310) = 128.01$, $p < .001$]. Recall increased significantly between both Day 1 and Day 2 [$t_1(29) = -8.87$, $p < .001$; $t_2(159) = -9.48$, $p < .001$], and Day 2 and Day 8 [$t_1(29) = -5.97$, $p < .001$; $t_2(159) = -6.59$, $p < .001$]. There was additionally a main effect of condition, which was significant by items but not by participants [$F_1(1, 25) = 1.38$, $p = .25$; $F_2(1, 155) = 5.55$, $p < .05$]. The by-item recall of picture-present words was higher than that of form-only words overall (picture present by-items, $M = 15.45\%$, $SD = 11.87$; form only, $M = 12.95\%$, $SD = 12.84$; $t_2(159) = -2.25$, $p < .05$). The interaction between training condition and day of testing did not reach significance [$F_1 = 1.59$, $p = .21$; $F_2 = 2.35$, $p = .097$]. In sum, the free recall analysis indicated a significant benefit in the percentage of items recalled both 24 hours and one week after training. Figure 5 shows the untransformed percentages.

Recognition memory

Recognition d′. Accuracy in the recognition of the trained words was analysed using signal detection measures (d', Snodgrass & Corwin, 1988). Novel word recognition was measured by subtracting z-transformed rates of false alarms from z-transformed rates of hits. Trials with no response (0.69% of all trials) and responses faster than 300 ms and slower than 2500 ms (0.92% of all trials) were excluded from participants' d' calculation. Recognition d' was then submitted to separate Condition (picture present, form only) × Day of testing (Day 1, Day 2, Day 8) repeated measures ANOVAs for participants (F_1) and items (F_2). There was a significant effect of day only [$F_1(2, 50) = 36.37$, $p < .001$; $F_2(2, 310) = 76.77$, $p < .001$]. Recognition sensitivity increased between both Day 1 and Day 2 [$t_1(29) = -5.84$, $p < .001$; $t_2(159) = -6.38$, $p < .001$], and between Day 2 and Day 8 [$t_1(29) = -3.37$, $p < .05$; $t_2(159) = -6.12$, $p < .001$]. There was no significant effect of condition on recognition sensitivity, or a Condition × Day interaction (Fs < 1, ps > .4). There was thus a significant enhancement of

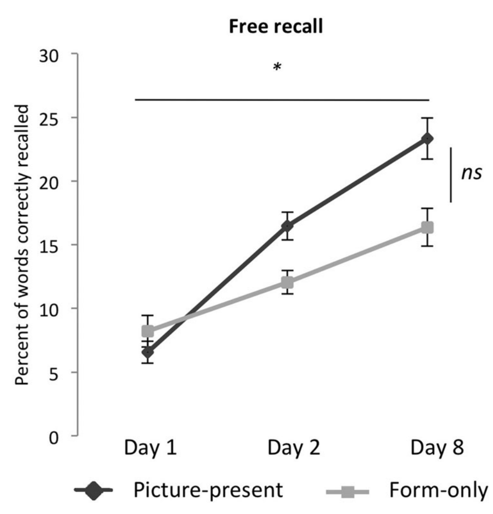

Figure 5. *Free recall performance across each day of testing.*

recognition memory on each day of testing in both conditions, with no impact of training condition. Table 3 shows the average recognition d' over subjects and items.

Recognition speed. Accurate reaction times (81.29% of trials) were submitted to by-participant and by-item ANOVAs, with the factors of condition (picture present, form only) and day (Day 1, Day 2, Day 8). These analyses yielded a significant main effect of day only [$F_1(2, 50) = 9.74$, $p < .001$; $F_2(2, 310) = 113.41$, $p < .001$], in which responses sped up on each day of testing [Day 1 to Day 2: $t_1(29) = 1.90$, $p = .067$, $t_2(159) = 5.98$, $p < .001$; Day 2 to Day 8: $t_1(29) = 3.19$, $p < .01$, $t_2(159) = 9.83$, $p < .001$]. The main effect of condition, and Condition × Day interaction, was not significant (all Fs < 1, ps $> .5$). Recognition speed thus increased on each day of testing and was unaffected by training condition. Table 3 presents the reaction time data.

Discussion

The current study addressed whether the provision of semantic information in learning new spoken words impacts on the time-course with which those new words are integrated with existing lexical knowledge. Previous research has suggested that the provision of semantic information during novel word learning can delay the time-course of lexical integration (Dumay et al., 2004; Takashima et al, 2014). This delay could reflect important limitations of the lexical integration process; specifically, it could be that the integration of semantic information requires a more gradual time-course due to the density of existing semantic networks (e.g., McClelland, 2013). However, this delay might also arise as a consequence of semantic information pulling the attentional focus away from phonological information during learning. Thus, in this study we investigated whether a focus on the phonological processing of semantically associated words could enable an equivalent lexicalization time-course to novel words acquired via phonological training alone.

In an extension of the methodology used by Takashima et al. (2014), participants learnt novel spoken words in a phoneme monitoring task, in which half of the novel words were consistently associated with a picture referent. Critically, participants were instructed to learn the spoken word forms, with no explicit instruction to learn the picture referents. Overall, the study yielded three key findings, with the overall findings summarized in Table 4. First, an equivalent lexical integration time-course was obtained for both picture-present and form-only words. Second, correlational analyses suggested that greater phonemic attention during learning supported stronger declarative memory of the new words, which was in turn tied to larger lexical competition effects following one week of consolidation. Third, in contrast to previous studies (e.g., Henderson, Weighall, & Gaskell, 2013; Takashima et al., 2014), there was no robust semantic benefit across measures of declarative word knowledge even though the evidence showed that participants had learned and retained the associations between novel words and their picture referents. Taken together, these findings suggest that the manner in which novel words are initially acquired can impact upon subsequent lexical integration.

Slower pause detection latencies emerged for both novel word conditions following one week of consolidation, in contrast to the 24-hour time-course typically observed for items trained under form-only conditions (e.g., Davis et al., 2009; Dumay & Gaskell, 2007, 2012; Henderson, Weighall, et al., 2013; Takashima et al., 2014). An important consideration is thus whether the current data reflect a delay in the form-only words' lexicalization, rather than more efficient lexicalization of the picture-present words. Lexicalization may have emerged over one week in the current study due to relatively weaker representations of the newly learnt words; indeed, recognition memory at the 24-hour test in the current study was substantially below that of Takashima et al. (75% vs. 95%). Critically, however, these memory constraints should have affected both conditions equally, as there was no difference between the novel word groups in recognition memory.

Table 3. *Recognition memory task performance*

Recognition memory	Day 1 test		Day 2 test		Day 8 test	
	Accuracy (d′)	RT	Accuracy (d′)	RT	Accuracy (d′)	RT
Picture present	1.45 (0.81)	1295 (332)	2.24 (1.17)	1206 (321)	2.65 (1.32)	1121 (294)
Form only	1.51 (0.80)	1285 (341)	2.25 (1.16)	1204 (318)	2.80 (1.48)	1135 (306)

Note: These data are the by-participant averages, with standard deviations shown in parentheses. RT = reaction time.

Overall, the equivalent lexical integration time-course for both picture-present and form-only words thus suggests that there was no relative lexicalization advantage for form-only novel words when equating the learning goals with picture-present novel words.

While evidence of lexical competition arising as a result of the trained items did not emerge until one week after training, it is of interest to note that shadowing performance for trained items showed an advantage immediately after learning. We believe that this pattern of results nicely reflects the distinction between lexical configuration and lexical engagement proposed by Leach and Samuel (2007). In this account, lexical configuration is factual knowledge about a new word (i.e., its phonological form and meaning), whilst lexical engagement is the influence of new words on the processing of existing lexical items (i.e., lexical competition). The shadowing and lexical competition data reinforce the distinction between having immediate access to the stored phonological form of a new word and the slower integration of this form with existing knowledge. A comparable result was observed by Henderson, Weighall, and Gaskell (2013), in which semantically associated and form-only novel words showed equivalent lexical competition effects, but with a declarative memory benefit for words learned with semantic information one week after learning (measured by cued recall). These data together support the distinction between factual knowledge about a new word and the engagement of this new word with existing lexical items.

Table 4. *Summary of the findings, based on the effect of condition and day on each test*

Word learning measure	Effect of Condition?		Effect of Day?	
	By-participants	By-items	By-participants	By-items
Lexicalization	No	No	Yes Lexicalization on Day 8	Yes Lexicalization on Day 8
Shadowing RTs	No	No	Yes Faster RTs on Day 2 than Day 1	Yes Faster RTs on Day 2 than Day 1
Free recall accuracy	No	Yes Higher recall of picture-present words	Yes Accuracy increased over each day	Yes Accuracy increased over each day
Recognition d'	No	No	Yes Accuracy increased over each day	Yes Accuracy increased over each day
Recognition RTs	No	No	Yes Faster over each day	Yes Faster over each day

Note: RT = reaction time.

One interesting aspect of our data in relation to Takashima et al. (2014) concerns the effect of picture associations on declarative memory. In Takashima et al. (2014), the picture-present words showed higher free recall accuracy and a greater overnight improvement in recognition accuracy than the form-only words. In contrast, the current data show no declarative memory advantage for the picture-present words. Indeed, whilst participants successfully acquired the picture–word associations in the current study, as indicated by the association memory task (with performance at 70% immediately after learning), these associations failed to benefit the strength of new word representations (recognition memory) or their retrieval (free recall). One possibility is that the learning goal of acquiring the new word forms only (and not the picture associations) may have attenuated any semantic advantage. The notion that learning goals can influence explicit knowledge of new words is consistent with similar reports in the literature. For example, Rodd et al. (2012) taught participants existing words with new meanings, which were either related or unrelated to the existing meaning. An advantage for learning the related meanings emerged only when participants explicitly focused on learning the new word–meaning mappings. This pattern of data is consistent with the proposal that learning goals may impact upon the extent of semantic recruitment in the encoding and subsequent retrieval of novel words.

Identifying a shared structure between new and existing knowledge is proposed by the CLS account (McClelland et al., 1995) as a core tenet of interleaving new with existing representations. It follows that new word representations encoded with a greater degree of phonological detail may show faster lexicalization than new words with poorly encoded phonological detail, by new word representations being better able to utilize the phonological structure of existing words in order to enter into competition during spoken word recognition. The current findings are consistent with this proposal: participants with stronger recognition memory at the initial test showed larger lexical competition effects at the one-week test, and stronger recognition memory at the initial test was tied to higher accuracy in phoneme detection during training. These correlational analyses suggest that the degree of phonological processing may support the strength of explicit new word memories, and stronger new word memories with such phonological detail may thus enable lexicalization. However, an additional possibility warrants consideration. Lexicalization was measured using pause detection, due to its sensitivity to online lexical activity during spoken word recognition (e.g., Mattys & Clark, 2002; Mattys, Pleydell-Pearce, Melhorn, & Whitecross, 2005). Spoken word recognition is a highly automatized perceptual skill, which draws on the phonological structure of lexical representations to evoke competition between phonologically overlapping neighbours. The degree of phonological processing subserving learning may thus be important for lexical integration, but critically only when the lexicalization test necessitates fine-grained phonological knowledge in such a way. The current findings thus indicate that the type of encoding supporting novel word learning can influence subsequent lexicalization, but the way in which the type of encoding pertains to the measure of lexicalization used remains to be addressed.

The current study reexamined whether the provision of semantic information during training impacts upon the time-course of lexical integration. The data support the conclusion that semantic information does not slow the time-course of lexical integration, provided that phonological information is recruited sufficiently well during training. More broadly, the current study aligns with emerging reports suggesting that the manner in which novel words are acquired can influence the subsequent lexicalization process (e.g., Coutanche & Thompson-Schill, 2014; Fernandes et al., 2009; Szmalec et al., 2012). Three main findings align with this conclusion: the concurrent emergence of lexical competition for novel words acquired both with and without a picture present in contrast to Takashima et al. (2014), the magnitude of the lexical competition effect being constrained by explicit recognition immediately after learning, and the positive correlation between explicit recognition and accuracy during the phonological training task. A key question stemming from this work concerns the precise mechanisms by which the integration of new and existing words is supported by phonological detail in the initial representations of new words. Critically, the constraints placed on lexical integration by both the strength and type of initial learning point to the importance of effective training for the successful integration of old and new knowledge.

Supplemental material

Supplemental content is available via the "Supplemental" tab on the article's online page (http://dx.doi.org/10.1080/17470218.2015.1079226).

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