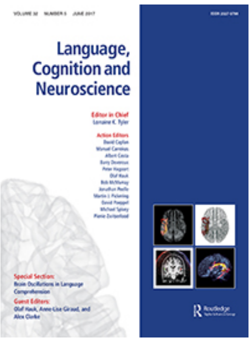

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Learning new meanings for known words: biphasic effects of prior knowledge

Xiaoping Fang, Charles Perfetti and Joseph Stafura

Learning Research and Development Center, Center for the Neural Basis of Cognition, University of Pittsburgh, Pittsburgh, PA, USA

ABSTRACT
Long after knowing the meaning of roller-“skate”, one may learn that “skate” is also a kind of fish. Such learning of new meanings for familiar words involves two potentially contrasting processes: form-based familiarity may facilitate the learning, and meaning-based interference may be inhibitory. We had native speakers learn new meanings for familiar and less familiar words, as well as for unfamiliar (novel) words. Tracking learning at several points revealed a biphasic pattern: higher learning rates and greater learning efficiency for familiar words relative to novel words early in learning and a reversal of this pattern later. After meaning learning, lexical access to familiar, but not to less familiar, words became faster than exposure controls. Overall, the results suggest that form-based familiarity facilitates learning earlier, while meaning-based interference becomes more influential later. The co-activation of new and old meanings during learning may play a role in lexicalisation of new meanings.

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KEYWORDS
Word learning; word frequency; familiarity; learning efficiency; lexicalisation

Introduction

Throughout the life span, people continuously update their knowledge of words. In addition to adding new words to their mental lexicon, they refine and add new meanings to already established word representations. The first kind of learning – new forms with new meanings – has received considerable attention in research (for recent reviews, see Gaskell & Ellis, 2009; McMurray, Horst, & Samuelson, 2012); learning new meanings for already-known word forms (Casenhiser, 2005; Rodd et al., 2012; Storkel & Maekawa, 2005) has been less studied. Often the new meaning is related to the one already known, as when one learns to extend the meaning of “normal” to statistical distributions. Sometimes, one learns a meaning unrelated to the known meaning, as when one learns that “skate” is also a kind of fish. Learning new meanings for existing word forms is potentially more complex, because the existence of a prior meaning can create a condition of interference in the learning of the new meaning. In order to assess the consequences of having already established meanings, we examined both new word learning (novel form, new meaning) and new meaning learning (known form, new meaning).

Some evidence suggests that learning a second meaning for a known word should be easier than learning a new word (Storkel & Maekawa, 2005; Storkel, Maekawa, & Aschenbrenner, 2013). According to Storkel and colleagues, familiarity with word forms facilitates learning of new meanings, because more attention can be recruited for learning the association between words and new meanings. This argument is also supported by the findings that learning new meanings for novel words benefits from prior exposure to novel word forms (Adlof, Frishkoff, Dandy, & Perfetti, 2016; Graf Estes, Evans, Alibali, & Saffran, 2007). If word forms and meanings are both novel, however, the learner must acquire both at the same time, and cannot bootstrap meaning on form (or vice versa). This familiarity advantage hypothesis therefore predicts enhanced learning efficiency when learners are at least somewhat familiar with a word, relative to when a word is completely unfamiliar.

However, an alternative perspective suggests a familiarity disadvantage: A second meaning for a known word should be harder to learn than a novel meaning for a novel word due to competition from the old meaning. One might also assume that an additional disadvantage arises from a violation of a one-to-one mapping between word form and meaning (Casenhiser, 2005; Doherty, 2004; Mazzocco, 1997). As discussed in Storkel and Maekawa (2005), evidence for the familiarity advantage hypothesis comes mainly from results of picture naming tasks. However, evidence supporting the disadvantage hypothesis comes from reference identification tasks that required participants to choose the correct meanings from multiple alternatives and focused on

CONTACT Charles Perfetti perfetti@pitt.edu
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testing the associations between words and new meanings. These tasks differ in the pressure they place on retrieving a novel word form, which is high in picture naming and low in forced selection of meanings. While poor performance in reference identification tasks may be primarily driven by poor knowledge of word-meaning associations, the observed advantage for known words in picture naming may reflect low accessibility to novel word forms rather than an advantage bestowed by the semantics of known words. A task that draws on new meanings of known words requires resolution of semantic competition between old and new meaning, especially when old meanings are more dominant and can be automatically activated (Chwilla & Kolk, 2003; Simpson, 1981).

Evidence for both familiarity advantage and disadvantage hypotheses comes from studies on young children (aged 3–5) (Casenhiser, 2005; Mazzocco, 1997; Storkel & Maekawa, 2005; Storkel et al., 2013). However, acquiring new meanings is a life-long process and studies of adults, who may take advantage of larger vocabularies and metacognitive strategies, are also informative. Particularly relevant to the issues we address is a study by Rodd et al. (2012), who taught adults new meanings for familiar words, manipulating the semantic relatedness between old and new meanings. In a recall task, participants performed better on the trained related meanings than the unrelated meanings. This result suggests that competition from the old and dominant meanings leads to difficulty for the learning and retrieval of new meanings. From this, it seems to follow that competition would be even stronger for familiar words than less familiar words, given that the previously established connections between word forms and original meanings are stronger in the case of familiar words (Perfetti, 2007).

Rather than framing the issue as two opposing hypotheses, we suggest a single framework that includes a biphasic time course for facilitative and interfering effects. Because familiarity with a word form increases with learning, the initial advantage of form familiarity should diminish, whereas the interference between old and new meanings may remain high throughout learning, especially for the overlearned meanings of familiar or frequently used words. Thus, tracking learning to high levels over time and measuring learning gains at different learning stages can potentially distinguish the effects of form familiarity from those of meaning interference.

Conceptualising learning new meanings as a biphasic interaction of form-meaning connections over time leads to a perspective on lexicalisation, the integration of a new word into a learner's functional lexicon. According to the complementary learning systems, or CLS account, initial acquisition of word knowledge is supported by a rapid, hippocampal-based learning, and lexicalisation requires offline consolidation of information with existing long-term knowledge stored in the neocortex (Davis & Gaskell, 2009; McClelland, McNaughton, & O'Reilly, 1995). The necessity of offline consolidation for lexicalisation of novel words has been supported by various studies (Bowers, Davis, & Hanley, 2005; Gaskell & Dumay, 2003; Qiao & Forster, 2013; Tamminen & Gaskell, 2013). However, some recent studies reported that newly learned words can be lexicalised immediately when existing words with similar pronunciations (Lindsay & Gaskell, 2013) or pictures related to the meanings of novel words (Coutanche & Thompson-Schill, 2014) were presented. In Coutanche and Thompson-Schill (2014), the presence of knowledge (i.e. pictures of familiar animals) was essential for the immediate lexicalisation of novel words. In such learning situations, the co-activation or interaction between new and existing knowledge is enhanced, which may make immediate lexicalisation possible.

Although most studies of lexicalisation have studied the addition of a new word to the learner's lexicon, Rodd et al. (2012) examined a similar lexicalisation process when new meanings are learned for existing words. They found shorter lexical decision times of words that had been paired with related new meanings compared to those paired with unrelated new meanings after a four-day intensive learning period. However, this difference was found only in a learning condition that required participants to use the training words in a new context; this learning effect did not occur after a six-day "superficial" learning period, which required participants to perform rating tasks about the new meanings. However, it remains to be seen whether a change in lexical accessibility, one of the ways to measure lexicalisation (Rodd et al., 2012), can occur on the day of learning. This may be possible because old meanings are obligatorily activated in the presence of training words, leading to the co-activation between new and existing word knowledge during the learning phase. In addition, how strongly old and new meanings co-activate or interact may be different for familiar and less familiar words, and as a result, word familiarity may also affect lexicalisation of new meanings.

In summary, the present study aimed to test the effects of word familiarity on learning new meanings that are unrelated to existing meanings. We had participants learn new meanings for words of three levels of familiarity – familiar (high frequency) words, less familiar (low frequency) words, and unfamiliar (novel) words (see Table 1 for examples). Although subjective familiarity and objective word frequency are not equivalent

Table 1. Examples of stimuli in different condition.

Condition	Form	Definition
Meaning condition		
High-frequency words	weapon	marked on the calendar
Low-frequency words	exodus	with a rough surface
Novel word	attave	having a large audience
Exposure condition		
High-frequency words	guilty	******************
Low-frequency words	fiscal	******************

(Gernsbacher, 1984; Graves, Grabowski, Mehta, & Gordon, 2007; Reichle & Perfetti, 2003), word frequency is one of the best objective indexes of word familiarity (Brown & Watson, 1987). To distinguish the influence of meaning learning from recent exposure to known words, we included exposure control conditions, which consisted of high- and low-frequency words that were not paired with new meanings. Finally, in contrast to previous studies, which have recorded only participants' learning outcome and/or controlled the number of exposures to trained words (e.g. Mazzocco, 1997; Storkel et al., 2013), we allowed participants to study items at their own pace. This procedure enables study time to be measured and used as part of an indicator of individual learning efficiency; it also enables detection of shifts in learner's study time and learning efficiency over trials. In addition to measuring study time across learning time points, we measured performance in meaning generation across time points to capture incremental learning. The learning efficiency measure combined the study time and meaning generation measures. The familiarity advantage hypothesis makes the following prediction for high-frequency words during learning: reduced study times, better performance in the meaning generation task, and higher learning efficiency; the disadvantage hypothesis makes the same predictions for novel, or unfamiliar, words. However, these effect may not be mutually exclusive. The biphasic learning hypotheses predicts early facilitative effects followed by later emerging interference effects during learning.

After learning, participants performed a series of tasks designed to tap encoding and retrieval of different aspects of word knowledge. First, a word-to-meaning matching task was used to test the recognition of the associations between words and their newly learned meanings. Second, we used a semantic relatedness task in which words were paired with words that were related to the new meanings but not presented during learning. The task would require the resolution of semantic competition to retrieve the newly learned meanings, and therefore would provide the best opportunity for retrieval interference from the old and dominant meaning. Highly familiar words may face stronger interference from old meanings than less familiar words do and both should produce more interference than unfamiliar words.

On the possibility that lexicalisation of new meanings can be reflected in lexical access of known words, we had participants perform two lexical decision tasks on high- and low-frequency words – including words with new meanings and exposure controls – before and right after the learning phase. Lexical accessibility of words with new meanings and exposure controls should be comparable before learning, and the difference between the two learning conditions in lexical accessibility after the learning provides some evidence of the immediate lexicalisation of new meanings. If new meanings are lexicalised, a larger number of meaning features should be available, and lexical access may occur more rapidly (Joordens & Besner, 1994; Kawamoto, Farrar, & Kello, 1994), although there is also evidence that lexical access can slow down when meanings are unrelated (Rodd, Gaskell, & Marslen-Wilson, 2002). In the case of learning new meanings, the original meaning of a highly familiar word receives stronger activation compared with that of a less familiar word. Thus, the stronger co-activation of the learned meaning with the original meaning may lead to lexicalisation of the new meaning for a highly familiar word more than for a less familiar word. If so, then lexical decisions to high-frequency words with new meanings, but not low-frequency words with new meanings, will be faster relative to their exposure controls after learning.

Methods

Participants

Twenty-five right-handed native English speakers (14 females, mean age = 19.34, ranged from 18 to 31 years) from the University of Pittsburgh Psychology Department subject pool participated in the study. All had normal or corrected-to-normal vision and none had been diagnosed with any learning disability. Participants provided written informed consent before the experiment and received course credits for their time. All experimental procedures were carried out with the approval of the University of Pittsburgh Institutional Review Board.

Stimuli

Trained words. Forty high-frequency (above 30 per million) words and 40 low-frequency (below 1 per million) words were selected from the SUBTL-US database (Brysbaert & New, 2009). According to

Wordsmyth English Dictionary--Thesaurus (Parks, Ray, & Bland, 1998), each of the trained words had only one meaning, while sometimes having more than one related "senses". To minimise the influence from word neighbours (Storkel, Armbruster, & Hogan, 2006), the trained words had zero or very few orthographic neighbours (69 words had zero neighbour, 9 words had one neighbour each, and 2 words had two neighbours) and word frequency of trained words with neighbours was always higher than their neighbour(s). High-frequency words included 15 nouns, 13 verbs, and 12 adjectives; low-frequency words included 14 nouns, 13 verbs, and 13 adjectives. Half of the high and half of the low-frequency words were paired with new meanings, and the other half were used as exposure controls, with the assignment of words to meaning or control conditions counterbalanced between participants. Another 20 pronounceable pseudowords (i.e. novel words), which had no word neighbours, were also paired with meanings. Examples of the trained words can be found in Table 1. In order to establish word familiarity ratings for this population, 23 undergraduates from the same subject pool, who did not participate in any other part of the study, were asked to rate how familiar they were with each of the training words from 1 (unfamiliar) to 6 (familiar). High-frequency words were, on average, rated as more familiar than low-frequency words ($p < .001$), and both types of real word were rated as more familiar than novel words ($ps < .001$). The three types of trained words were matched on the number of syllables, word length in letters, and bigram frequency; high and low-frequency words were additionally matched on number of senses and concreteness, to reduce potential confounding from lexical characteristics and old meanings (see Table 2 for lexical characteristics, and Appendix A for a full list of trained words).

Definitions and probes. Sixty new meanings were created by the experimenters and cast into short definitions of two to six words (mean 3.65). These definitions were created to allow realistic conceptual mappings but with no overlap with existing words. The definitions could be used to describe objects (17), plants or animals (15), human beings (18), events (5), or more than one category (5). The pairing between trained words and definitions was counterbalanced across participants such that each definition was paired with a high-frequency word for one third of participants, a low-frequency word for one third of participants, and a novel word for one third of participants. To assess any inadvertent relation of the new meaning of a word to its actual meaning, we carried out a term-to-document Latent Semantic Analysis (LSA, http://lsa.colorado.edu), measuring semantic similarity between two semantic spaces (Landauer & Dumais, 1997). The results showed very low LSA cosine value or low similarity for both high- and low-frequency words with a mean LSA value of .007 (SD = .047) and .006 (SD = .054), respectively, indicating no relationship of the new meanings to the real meanings. Additionally, the list of word-meaning mappings was independently reviewed by three native English speakers to confirm that they were unrelated (See Table 1 for examples). For each definition, we created a meaning probe (for use in the semantic judgment task) that was related to the definition but did not explicitly occur in it. The probes had a mean word frequency of 43.83 per million and mean length of 5.9. (See Appendix B for full list of definitions and probes)

Word and nonword fillers in lexical decision tasks. In addition to the 80 critical words, another 160 real words were included as filler words – 40 high-frequency, 40 low-frequency, and 80 mid-frequency words ranging from 1 to 30 occurrences per million (Brysbaert & New, 2009). Half of the filler words in each frequency range were presented in the before-learning lexical decision task, the other half in the after-learning task. In addition to words, 240 pronounceable nonwords were created by changing one letter of real words that were not used in any other part of the study; 80 of these were presented in both before- and after-learning tasks so that the same number of words and nonwords were repeated in the 2 tasks, 80 were presented only in the before-learning task while 80 only in the after-learning task. Therefore, there were 160 words and 160 nonwords in each lexical decision task.

Table 2. Descriptive statistics of training words.

	N	Frequency	Familiarity	NSenses	Concreteness	Length	Log_BG	NSyllable
High-frequency words	40	83.81 (70.09)	5.93 (0.10)	2.73 (0.99)	3.33 (1.21)	6.88 (0.85)	7.48 (0.39)	2.20 (0.56)
Low-frequency words	40	0.34 (0.26)	4.19 (0.44)	2.50 (1.11)	3.27 (0.98)	6.98 (0.89)	7.41 (0.36)	2.35 (0.58)
Novel word	20	–	1.12 (0.39)	–	–	6.95 (0.83)	7.45 (0.33)	2.35 (0.59)

Notes: Mean and SD (in parentheses) were reported. Word frequency was obtained from SUBTL frequency (Brysbaert & New, 2009); Nsenses represents number of senses and was obtained from WordSmyth; Log_BG (log of mean bigram frequency) and NSyllable (number of syllables) were obtained from English Lexicon Project (Balota et al., 2007). Concreteness was rated from 1 (abstract) to 6 (concrete) by 18 raters from Amazon Mechanical Turk as a previous study did (Brysbaert, Warriner, & Kuperman, 2013). Except word frequency and word familiarity ratings, there is no any significant difference across conditions ($ps > .20$).

Procedure

As shown in Figure 1, participants first performed a lexical decision task, and then experienced six complete learning trials or exposures in the learning phase, each presenting all trained words and their new meanings once. Following the 2nd, 4th, and 6th exposures, they took a meaning generation test. After the learning phase, participants performed another lexical decision task, a form-meaning matching task, and a semantic relatedness judgment task.

Lexical decision task 1. Participants were asked to judge whether each presented letter string was a real word as quickly and as accurately as possible by pressing buttons with their left or right index fingers (response keys were counterbalanced between participants). Each trial started with a central fixation for 500 ms, followed by a word or a nonword. The next trial was initiated immediately after a response, which was required to occur within 1500 ms. Reaction times and accuracy were recorded. The task began with a short practice session.

Learning paradigm. For the learning trials, participants were instructed that they were to learn new meanings for words, some of which were familiar and had existing meanings, some of which were less familiar or unfamiliar. Participants were also told that they would encounter some words that were not paired with any new meanings (i.e. exposure controls). Participants had six learning trials or exposures for each word. In each trial, a fixation was presented for 500 ms, followed immediately by visual presentation of a trained word. Participants pressed the space bar when they were ready to learn its meaning, which caused the appearance of either a definition (for trained words with new meanings) or a string of stars ("************") (for exposure controls). When participants were ready to learn the next word, they pressed the space bar to move on. The study time on each word – including word reading and definition – was recorded during the self-paced learning. Starting on the second learning trial (i.e. after one exposure to all words) participants were encouraged to recall the meanings when they saw the words, but no explicit responses were required or recorded. This implicit retrieval instruction was included to facilitate learning (Bjork, Dunlosky, & Kornell, 2013).

Meaning generation tests. After the 2nd, 4th, and 6th exposures, participants took a meaning generation test based on a one-third sample of the training words. Six or seven words for each condition were randomly tested at each of three tests and each word was tested only once. This was part of a sampling strategy that prevented participants from knowing which words would be tested, while preventing the prohibitive length of time that would be required to test all the words. In each trial, a word was presented in the centre of the screen, and participants were asked to type its meaning within 15 seconds. If a word did not have a new meaning, as was the case with exposure controls, the participants were instructed to type "n" for "none"; if they believed they had been presented a new meaning for the word but were unable to remember it, they were instructed to type "?".

Lexical decision task 2. The procedure was identical to that in Lexical decision task 1.

Form-meaning matching test. The matching task required participants to match the 60 trained words with their newly learned meanings. Thirty trained words (10 from each type) and 36 possible definitions (including 6 that were definitions of trained words on the other page) were presented in two separate columns on each of the two pages. The order of words and that of definitions were pseudo-randomised so that no more than three words or definitions from the same condition occurred consecutively. Definitions were numbered from 1 to 36, and for each word participants were asked to write down the number corresponding to its definition. Participants were told that on each page there were six extra definitions that would not matched any words on the same page.

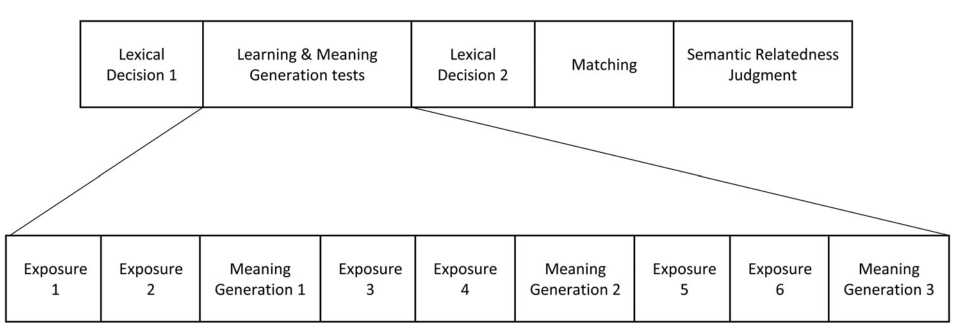

Figure 1. Schematic diagram of the experimental procedure.

Semantic relatedness judgment task. The semantic judgment task assessed whether the retrieval of new meanings was influenced by interference from old meanings. Participants viewed word pairs and decided whether they were semantically related. The first word was a trained word and the second word was a meaning probe, either related or unrelated to the new meaning of the preceding trained words. Unrelated word pairs were generated by re-pairing trained words and meaning probes (e.g. a related meaning probe for one word became an unrelated probe for a different word). Therefore, each probe and each training word was presented twice: once in a related pair and once in an unrelated pair. A trial started with a central fixation for 500 ms, and then two words were presented one at a time. The first word was presented for 500 ms and the second word followed immediately. Participants were asked to judge whether each word pair was related or not, based on the new meanings that they just learned, by pressing "1" or "2" using their right index or middle fingers respectively. The next trial appeared immediately after the response or after 2500 ms elapsed. Both responses and reaction times were recorded.

Data analyses

Differences between conditions were tested using repeated-measures ANOVAs for each task separately. For reaction time data (in the lexical decision tasks and semantic relatedness judgment task), incorrect trials and trials with response times beyond 2.5 standard deviations from the mean or shorter than 200 ms were excluded. In the lexical decision tasks, differences between words with new meanings and their exposure controls were tested at each of the two time points using paired *t*-tests, for high and low-frequency words separately. Pair-wise comparisons were conducted to test the differences among three types of words in all other tasks, using within-subjects analyses. Bonferroni correction for multiple comparisons was used when applicable and only corrected *p* values are reported unless stated otherwise.

Results

Tracking learning

Study time. The Study Time for each word was defined as the total time (word reading + definition study) that participants spent on the word in each learning trial, and results are shown in Figure 2(a). Overall, participants spent less and less time learning the meanings across exposures (F_1 (2, 48) = 17.944, $p < .001$, $\eta_p^2 = .428$; F_2 (5, 485) = 379.973, $p < .001$, $\eta_p^2 = .794$) and the study time varied with word type (F_1 (2, 48) = 9.432, $p < .001$, $\eta_p^2 = .282$; F_2 (2, 117) = 3.984, $p = .021$, $\eta_p^2 = .064$). Overall all exposures, study times for high-frequency words ($p = .013$) and low-frequency words ($p < .001$) were shorter than novel words, but no reliable difference was found between high and low-frequency words ($p = .428$), even though there was an apparent difference at the third exposure ($p = .156$, see Figure 2(a)). However, word type and learning exposure did not interact with each other (F_1 (10, 48) = 1.455, $p = .157$, $\eta_p^2 = .057$; F_2 (10, 585) = 1.122, $p = .343$, $\eta_p^2 = .019$).

Meaning generation. Participants' responses were rated independently by two experimenters who were blind to the experimental conditions on a scale of 1

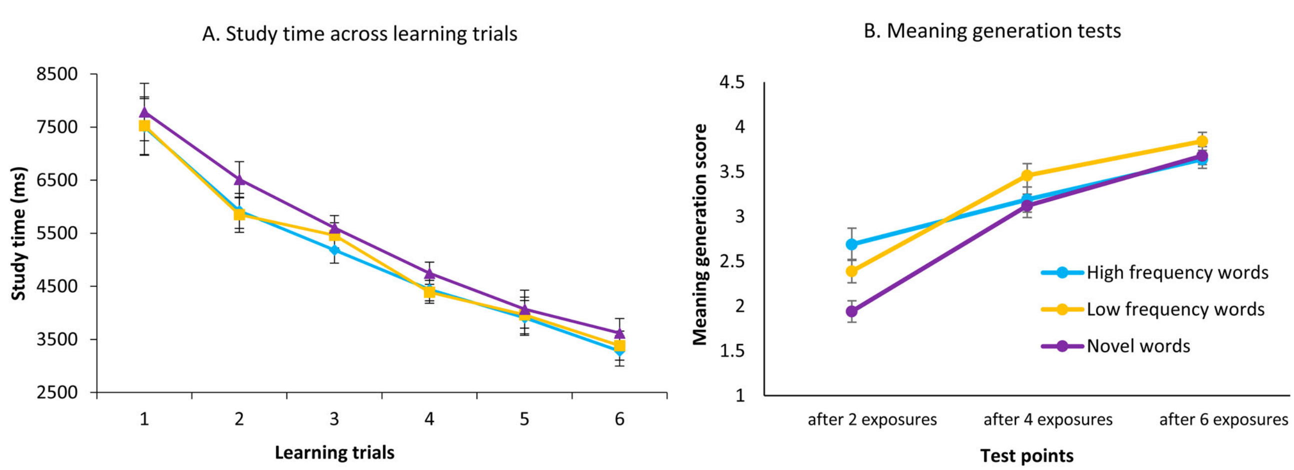

Figure 2. (a) Study time across six exposures. (b) Meaning generation tests after the second, fourth, and sixth exposures. Error bars show ± 1 SEM after between-subject variance is removed (Loftus & Masson, 1994). [To view this figure in color, please see the online version of this journal.]

Table 3. Accuracy in the matching test.

	Less successful learners ($n = 12$)	More successful learners ($n = 13$)	Overall ($n = 25$)
High-frequency words	0.813 (0.062)	0.977 (0.009)	0.898 (0.034)
Low-frequency words	0.734 (0.071)	0.981 (0.009)	0.862 (0.042)
Novel words	0.681 (0.066)	0.985 (0.012)	0.839 (0.044)

Notes: Mean and SEM (in parentheses) were reported. SEM was adjusted to remove between-subjects variance (Loftus & Masson, 1994).

(unrelated meaning) to 5 (the exact meaning),[1] and the ratings were then averaged for each item. The inter-rater correlation was .98. The time course of learning new meanings was evidenced by a significant increase of accuracy across the three test points (F_1 (2, 48) = 41.659, $p < .001$, $\eta_p^2 = .658$), as shown in Figure 2B. Related to our biphasic hypothesis, the interaction between word type and test point was significant (F_1 (2, 48) = 3.061, $p = .02$, $\eta_p^2 = .112$). After the first two exposures, participants performed better in meaning generation for high- and low-frequency words relative to novel words ($p = .008$ and $p = .004$ respectively), with no difference between high and low-frequency words ($p = .468$). Differences between conditions at subsequent test points were not significant ($ps > .10$). To better capture the interference effect in later learning phase while controlling the early learning outcome, improvements of learning across test points were calculated. The performance between adjacent test points (i.e. from test 1 to test 2, and from test 2 to test 3) did not show any significant main effect of word type ($ps > .05$), which might be related to the relatively small amount of learning overall after two exposures. Therefore, we focused on the improvement from test 1 to test 3 and defined the learning over the last four exposures as late learning. The improvement from test 1 to test 3 showed a significant main effect of word type (F_1 (2, 48) = 6.125, $p = .004$, $\eta_p^2 = .203$): meaning generation performance improved more for novel words (1.73) than for high-frequency words (0.94) ($p = .018$), with low-frequency words (1.46) intermediate and not significantly different from high-frequency words or novel words after correction ($ps > .14$, uncorrected $p = .047$ for high- vs. low-frequency words).

Learning efficiency. Participants spent as much time as they needed to study each word, thus producing study time differences across word types. In particular, participants spent more time on novel words throughout the learning phase. Such differences allow the use of a learning efficiency measure to capture the improvement of learning relative to study time. We were especially interested in learning efficiency in early trials (first two exposures), where we hypothesise both word encoding and associative learning (i.e. the learning of associations between words and new meanings) are involved compared with subsequent learning efficiency (last four exposures), when word encoding differences should have been reduced. Early learning efficiency was defined as the meaning generation score at test point 1 relative to mean study time (in seconds) of the first two exposures, and late learning efficiency as the improvement of meaning generation scores from test point 1 to test point 3 relative to mean study time of the last four exposures (as late learning in the meaning generation tests). At the early learning stage, the learning of both high- and low-frequency words was more efficient than for novel words ($ps < .01$). At the later stage, the pattern was reversed: the learning of novel words was more efficient than high-frequency words ($p = .026$), with low-frequency words in the middle and marginally different from high-frequency words (uncorrected $p = .025$). (See Figure 3)

Post-learning

Form-meaning matching

The matching test provides a measure of form-meaning association learning for all words after all six learning exposures. Accuracy in matching a trained word to its new definition was high but still affected by word type (F_1 (2, 48) = 3.359, $p = .043$, $\eta_p^2 = .123$; F_2 (2, 117) = 5.092, $p = .008$, $\eta_p^2 = .080$): there was a trend of familiarity advantage (see Table 3), although none of the pair-wise comparisons reached statistical significance ($ps > .10$).

Because a trend for a familiarity advantage may reflect individual differences related to learning, we carried out a post hoc analysis comparing more successful and less

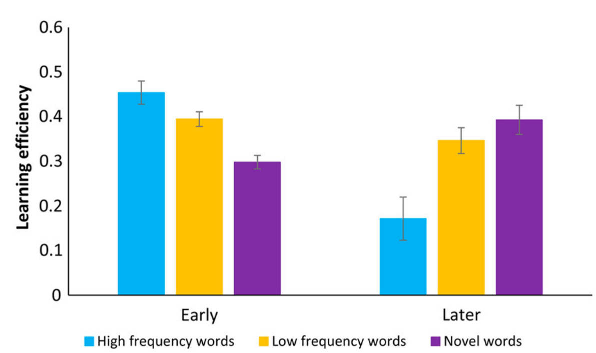

Figure 3. Learning efficiency in early and later learning. Learning efficiency is defined as the improvement of performance in meaning generation tests after the first two exposures (early) and over last four exposures (later) relative to study time (in seconds). Error bars show ± 1 SEM after between-subject variance is removed (Loftus & Masson, 1994). [To view this figure in color, please see the online version of this journal.]

successful learners. We took the final meaning generation task as a robust indicator of learning success (based on meaning retrieval rather than recognition). Those participants ($n = 13$) who were above average on this measure were classified as more successful learners, while the remaining ($n = 12$) were "less successful learners" (See Table 3). Within the more successful learners, accuracy was very high across all three types of word, with no differences among word type (F_1 (2, 22) = .118 $p = .830$, $\eta_p^2 = .015$; F_2 (2, 117) = .052, $p = .949$, $\eta_p^2 = .001$). Less successful learners showed a main effect of word type (F_1 (2, 24) = 5.004, $p = .029$, $\eta_p^2 = .313$; F_2 (2, 117) = 3.971, $p = .021$, $\eta_p^2 = .064$): They tended to perform better on high-frequency words than novel words ($p = .077$) and intermediately on low-frequency words ($ps > .10$).

Semantic relatedness judgments

The semantic relatedness judgment task, designed to assess the interaction between newly learned meanings and old meanings, showed effects of word type in both accuracy and decision times (see Figure 4). For accuracy, the main effect of word type was significant (F_1 (2, 48) = 3.742, $p = .031$, $\eta_p^2 = .135$; F_2 (2, 117) = 3.158, $p = .046$, η_p^2 = .051): High-frequency words produced lower accuracy than novel words ($p = .057$); low-frequency words were not different from high-frequency words or novel words ($ps > .10$). The overall accuracy for related word pairs was higher than unrelated word pairs (F_1 (1, 48) = 21.880, $p < .001$, $\eta_p^2 = .477$; F_2 (1, 117) = 41.094, $p < .001$, $\eta_p^2 = .260$), and the interaction between word type and relatedness was not significant (both F_1 and $F_2 < 1$). There was also a main effect of word type in decision times (F_1 (2, 48) = 33.402, $p < .001$, $\eta_p^2 = .582$; F_2 (2, 117) = 15.611, $p < .001$, $\eta_p^2 = .211$): High-frequency words showed longer decision times than both low-frequency words and novel words ($ps < .001$); low frequency and novel words did not differ reliably ($p > .90$). Decision times for related word pairs were shorter than unrelated pairs (F_1 (1, 24) = 7.943, $p = .010$, $\eta_p^2 = .249$; F_2 (2, 117) = 24.724, $p < .001$, $\eta_p^2 = .174$), and the interaction between relatedness and word type was not significant (F_1 (2, 48) = 1.548, $p = .223$, $\eta_p^2 = .061$; $F_2 < 1$).

Lexicalisation: lexical decision

The data were first analysed using a three-way repeated measure ANOVA with Word Frequency (high/low), Training Type (with new meanings/exposure controls) and Test Time (before/after training) as within-subject variables. As expected, the overall lexical decision times for high-frequency words were shorter (F_1 (1, 24) = 140.696, $p < .001$, $\eta_p^2 = .854$; F_2 (1, 70) = 117.396, $p < .001$, $\eta_p^2 = .601$), and accuracy was higher (F_1 (1, 24) = 60.212, $p < .001$, $\eta_p^2 = .715$; F_2 (1, 78) = 67.987, $p < .001$, $\eta_p^2 = .466$), compared to low-frequency words. After learning, the overall decision times became shorter (F_1 (1, 24) = 60.212, $p < .001$, $\eta_p^2 = .715$; F_2 (1, 78) = 67.987, $p < .001$, $\eta_p^2 = .466$) and accuracy became higher (F_1 (1, 24) = 60.212, $p < .001$, $\eta_p^2 = .715$; F_2 (1, 78) = 67.987, $p < .001$, $\eta_p^2 = .466$). In addition, low-frequency words showed a greater decrease in decision times (F_1 (1, 24) = 28.320, $p < .001$, $\eta_p^2 = .541$; F_2 (1, 78) = 32.160, $p < .001$, $\eta_p^2 = .292$) and a greater increase in accuracy (F_1 (1, 24) = 39.967, $p < .001$, $\eta_p^2 = .621$; F_2 (1, 78) = 58.016, $p < .001$, $\eta_p^2 = .427$), relative to changes on high-frequency words. Overall, reaction times for words under the two conditions of Training Type were comparable (F_1 (1, 24) = 1.525, $p = .229$, $\eta_p^2 = .060$; F_2 (1, 78) = 1.889, $p = .173$, $\eta_p^2 = .024$), however, the three-way interaction was marginally significant in item analysis (F_1 (1, 24) = .693, $p = .414$, $\eta_p^2 = .028$; F_1 (1, 78) = 2.977, $p = .088$, $\eta_p^2 = .037$)

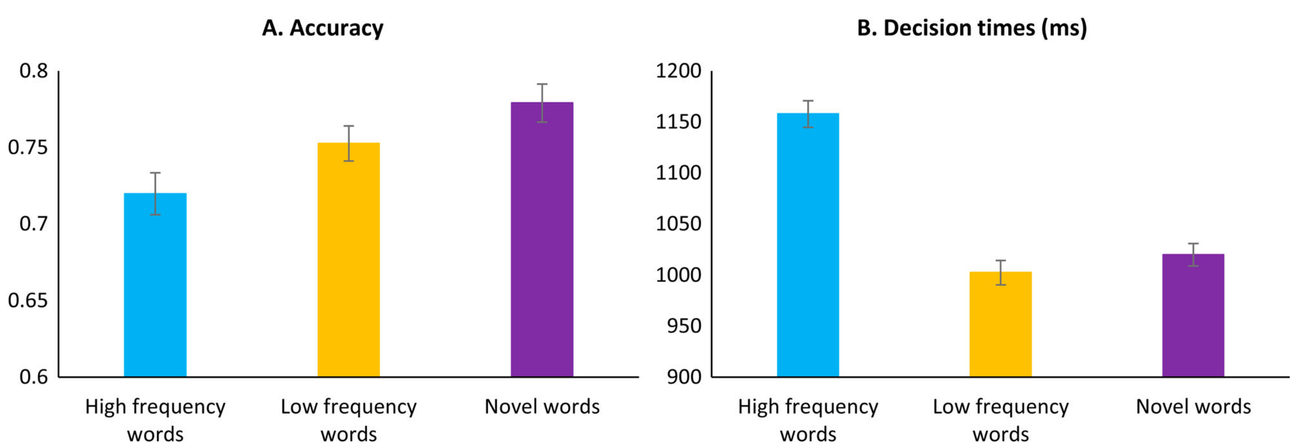

Figure 4. Accuracy and decision times in semantic relatedness judgment task. Error bars show ± 1 SEM after between-subject variance is removed (Loftus & Masson, 1994). [To view this figure in color, please see the online version of this journal.]

(accuracies were unaffected, both F_1 and $F_2 < 1$). All other interactions were not significant in reactions times or accuracies (*all Fs < 1*, except F_1 (1, 24) = *1.742*, $p = .199$, $\eta_p^2 = .068$ for the interaction between Training Type and Test Time in lexical decision times).

To test the hypothesis about how training (meaning learning vs. mere exposure) differentially affects the lexical access to high- and low-frequency words, we performed analyses on high- and low-frequency words separately. For each, we compared words across the two training conditions at both test points, and also tested the interaction between Training Type and Test Time. For high-frequency words, decision times for words with new meanings were shorter than those for exposure controls after learning ($p = .047$), but not before learning ($p = .535$), although the Training Type by Test Time interaction was marginally significant in the item analysis and not significant in the subject analysis (F_1 (1, 24) = 2.511, $p = .126$, $\eta_p^2 = .095$; F_2 (1, 39) = 3. 292, $p = .077$, $\eta_p^2 = .078$). For low-frequency words, decision times for words under the two training conditions were comparable both before ($p = .267$) and after ($p = .554$) learning, and the interaction between Training Type and Test Time was not significant (both F_1 and $F_2 < 1.1$, $ps > .70$). In terms of accuracy, high-frequency words were judged with a high level of accuracy in both meaning and exposure conditions at both test points (Before learning: 98% and 97%, $p = .382$; After learning: 98% and 99%, $p = .083$; $|F_1$ (1,24) = 3.000, $p = .096$, $\eta_p^2 = .111$; F2 (1, 39) = .418, $p = .552$, $\eta_p^2 = .011$); accuracy for the two types of low-frequency words was comparable at both time points (Before learning: 67% and 66%, $p = .705$; After learning: 86% and 86%, $p = .770$; both F_1 and $F_2 < 1$, $ps > .85$). Figure 5

Discussion

To investigate the influence of prior word knowledge on learning, the current study compared the learning of new meanings for trained words that vary in familiarity. The results showed a biphasic effect of word familiarity over the course of learning: higher learning rates and greater learning efficiency for familiar relative to unfamiliar words early in learning and a reversal of this pattern later in learning. In addition, after learning, lexical access to familiar words with new meanings became faster compared to their exposure controls, but no such effect occurred for less familiar words. Below, we discuss the implications of this pattern and its possible link to lexicalisation.

Facilitation and interference resulting from word familiarity

Learning new meanings for existing words, both high and low frequency, required less study time than that for novel words and also led to a better cued-recall performance in the meaning generation test and higher learning efficiency after only two exposures, which was the first test point. After the first two exposures, learning patterns show a marked reversal from this initial pattern, from a familiarity advantage to a disadvantage. Although less familiar words, especially novel words, may continue to require some extra encoding effort in the later learning phase, both learning gains from the second to the sixth exposure and learning efficiency over the last four exposures showed this pattern: novel > low frequency > high-frequency words. This pattern suggests a relative increasing cost of interference of old meanings as a

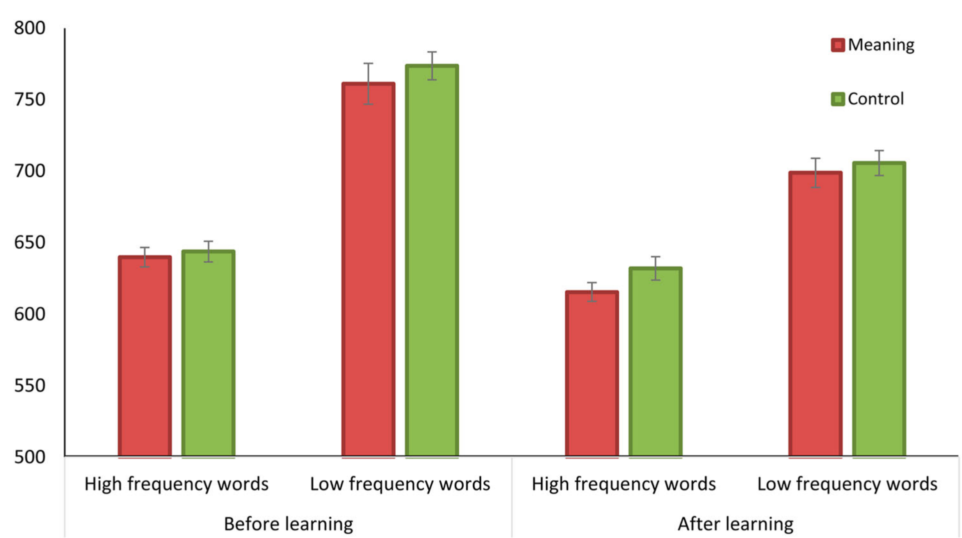

Figure 5. Reaction times (ms) in lexical decision tasks before and after training. Error bars show ± 1 SEM after between-subject variance is removed (Loftus & Masson, 1994). [To view this figure in color, please see the online version of this journal.]

function of familiarity, even though participants learned the three types of words to similar degrees by the end of the learning phase. We emphasise that the interference cost is relative to other factors in learning, especially form familiarity. Interference is present throughout learning, but its effects are long lasting and thus are more visible after other factors diminish in importance. Although the differences in learning gains are consistent with the explanation of relative increasing interference for familiar items, it is possible that the differences arise from differing initial levels of learning; that is, more room for improvement was available for less familiar words after the first test.

We think the interference explanation is more likely, because the results of the semantic relatedness judgment task showed longer times for judgments of familiar words. This semantic judgment task has been used in previous studies to show the result of word learning in a meaning transfer task (Mestres-Misse, Rodriguez-Fornells, & Munte, 2007; Perfetti, Wlotko, & Hart, 2005). In the present study, participants were able to make accurate relatedness judgments based on newly learned meanings, indicating they could retrieve new meanings in a transfer task. In addition, they showed interference in longer response times that depended on word frequency. Interference was greater for high-frequency words than low-frequency words, reflecting their more strongly associated meanings, which are activated rapidly and interfere with judgments based on new meanings.

The time course of the biphasic effect – how fast the familiarity advantage wanes or the familiarity disadvantage emerges – can vary across individuals, as suggested by a post hoc group analysis of performance in the matching task. Here, only less successful learners showed an advantage of word familiarity after the learning phase. This may indicate that these learners take more time to develop functionally specific representations of trained words, which impedes the encoding phase of learning especially for novel words. Thus when they were faced with a full set of trained words and definitions in the matching task, less successful learners' representations of individual low frequency and novel words were not discriminating enough to pair correctly with their meanings. This implies that studying word forms (especially those of low-frequency words and novel words) before meaning learning would reduce such individual differences.

Overall, the pattern of results show that form facilitation is strong early in learning; meaning interference, assumed to be strong throughout, then emerges as the dominant factor when form familiarity effects have diminished. The patterns of results support a single framework that includes a biphasic time course for facilitative and interfering effects.

The observed effects of word familiarity arise from varying word knowledge – spelling, pronunciation, and meaning, that participants have about different words; that is, the varying quality of lexical representations (Perfetti, 2007). Language experience yields a greater number of experiences with, and thus more knowledge for both form and meaning, for more frequent words. These words can then be readily encoded, which facilitates new learning, but also afford the strong activation of the words' meanings, inhibiting the formation of a new meaning association. This is the basis of the biphasic effects of word familiarity. The more stable familiarity advantage for real words over novel words, relative to that of high-frequency words over low-frequency words, can be attributed partially to the disproportionate boost in word familiarity that recent exposure has on low-frequency words (Forster & Davis, 1984; Rugg, 1990); this boost rapidly reduces the initial familiarity advantage for high-frequency words. However, the number of exposures in this experiment was not sufficient to extinguish the familiarity advantage of real words over novel words.

The biphasic pattern can be placed in a broader context of associative learning (Underwood, 1957; Underwood & Freund, 1968). Stimulus learning is a first stage in forming new associations. The availability of a familiar form minimises the "stimulus learning" component (e.g. learning of word forms) of paired associate learning, and therefore allows attention to be focused on associative learning, per se (e.g. associating word forms with new meanings), instead of being divided between the two processes. As associative learning proceeds, the unfamiliar form becomes more familiar and the initial advantage of familiarity wanes. At the same time, interference from a previously established association (e.g. original meaning) in the learning of a new association continues, and its effects emerge as a more influential factor at later stages of learning.

The biphasic patterns may help explain the conflicting results in previous studies in which participants reached different levels of learning when tested. Storkel and colleagues (2005, 2013) found higher learning rates for known words than novel words in picture naming tasks that produced only low levels of accuracy (8–38% and 4–24%, respectively), suggesting participants were still at an early learning phase. The advantage over known words is more evident when known words have a higher phonotactic probability (Storkel & Maekawa, 2005) or a higher word frequency (Storkel et al., 2013; but see Storkel & Maekawa, 2005). The benefit of higher quality word form representations on meaning acquisition can also be found in infants (Graf Estes et al., 2007; Hay, Pelucchi, Graf Estes, & Saffran, 2011) and adult beginning learners of second language (Cao et al., 2013). Interference emerges when participants reach a higher level of learning. Among the studies that report a familiarity disadvantage, participants have learned novel words pretty well (e.g. 72.5% in Casenhiser, 2005; 4.31 out of 6 words in Mazzocco, 1997) when tested even though participants showed low learning rate for familiar words (e.g. 11.25% in Casenhiser, 2005; 0.81 out of 6 words on average in Mazzocco, 1997). By tracking participants' learning and taking both task performance and study time into account, our findings reconcile these "inconsistent" results and reveal a dynamic interaction between facilitation from word form familiarity and interference from existing meanings on the learning outcomes.

Lexicalisation of new meanings

Although earlier studies emphasised the importance of offline consolidation on the lexicalisation of new knowledge, recent evidence demonstrates that consolidation is not necessary under conditions that promote connections to be made between existing knowledge and the new knowledge (Coutanche & Thompson-Schill, 2014; Lindsay & Gaskell, 2013). Our study created conditions that led to new knowledge and prior knowledge being co-activated during learning. This co-activation produces interference through competition between meanings; but over time, this continued co-activation may lead to the new meaning joining the old meaning as a component of the lexical entry – a less retrievable component that will become irretrievable without use. Lexicalisation that is strongly driven by the interaction between newly taught knowledge and existing knowledge may not depend on sleep (e.g. Lindsay & Gaskell, 2013) nor on any specific semantic relatedness between new and existing knowledge (Coutanche & Thompson-Schill, 2014). Any condition that causes the new and existing knowledge to be co-activated may be sufficient. It is interesting for this suggestion that in our lexical decision data high-frequency words, but not low-frequency words, were affected (i.e. speeded) by the learning of new meanings, although the effects were weak statistically. This frequency effect suggests that the stronger the interaction is, the more rapidly lexicalisation may occur. Following this hypothesis, boosting existing knowledge of less familiar words prior to the learning of new meanings through, for example, relearning old meanings, might enhance such interactions and be beneficial for learning.

Although the account of co-activation is plausible, we cannot claim that lexicalisation of meaning occurred in our experiment. It is possible that performance on all tasks, including lexical decision, was the result of episodic memory processes in which participants' responses were mediated by retrieval of the learning trials. Such an account would explain frequency effects by assuming that more familiar words somehow provide stronger retrieval cues for their learning trial episodes. Tasks that directly tap processing of old meanings would help distinguish between these alternatives.

Conclusion

We found that familiarity with word form facilitates the acquisition of new meanings for known words in early learning, while interference from the original meanings becomes more evident at a later phase of learning. This biphasic pattern thus includes facilitative and interfering effects of prior meanings within a single conceptual framework, at the centre of which is the co-activation of prior meanings and new meanings. Finally, this co-activation process may be important in the lexicalisation of new meanings.

Note

1. The definitions do not contain the same number of meaning features. To accommodate the variety of conceptual structures in our new meanings, we keyed scoring to the number of meaning features in the definition. The recall of all features earned five points. Partial credit was then proportional to number of features. Recalling one feature of two was worth more than recalling one feature of four. Since we counterbalanced the pairing between definitions and three types of words, and the raters were blind to the conditions, we believe this largely avoids confounds with number of features.

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ORCID

Joseph Stafura http://orcid.org/0000-0001-5616-6913

References

Adlof, S., Frishkoff, G., Dandy, J., & Perfetti, C. (2016). Effects of induced orthographic and semantic knowledge on subsequent learning: A test of the partial knowledge hypothesis. *Reading and Writing*, *29*(3), 475–500. doi:10.1007/s11145-015-9612-x

Balota, D. A., Yap, M. J., Cortese, M. J., Hutchison, K. A., Kessler, B., Loftis, B., … Treiman, R. (2007). The English lexicon project. *Behavior Research Methods*, *39*(3), 445–459.

Bjork, R. A., Dunlosky, J., & Kornell, N. (2013). Self-regulated learning: Beliefs, techniques, and illusions. *Annual Review of Psychology*, *64*, 417–444. doi:10.1146/annurev-psych-113011-143823

Bowers, J. S., Davis, C. J., & Hanley, D. A. (2005). Interfering neighbours: The impact of novel word learning on the identification of visually similar words. *Cognition*, *97*(3), B45–B54. doi:10.1016/j.cognition.2005.02.002

Brown, G. D., & Watson, F. L. (1987). First in, first out: Word learning age and spoken word frequency as predictors of word familiarity and word naming latency. *Memory & Cognition*, *15*(3), 208–216.

Brysbaert, M., & New, B. (2009). Moving beyond Kucera and Francis: A critical evaluation of current word frequency norms and the introduction of a new and improved word frequency measure for American English. *Behavior Research Methods*, *41*(4), 977–990. doi:10.3758/BRM.41.4.977

Brysbaert, M., Warriner, A. B., & Kuperman, V. (2013). Concreteness ratings for 40 thousand generally known English word lemmas. *Behavior Research Methods*, *46*(3), 904–911.

Cao, F., Vu, M., Chan, D. H., Lawrence, J. M., Harris, L. N., Guan, Q., … Perfetti, C. A. (2013). Writing affects the brain network of reading in Chinese: A functional magnetic resonance imaging study. *Human Brain Mapping*, *34*(7), 1670–1684. doi:10.1002/hbm.22017

Casenhiser, D. M. (2005). Children's resistance to homonymy: An experimental study of pseudohomonyms. *Journal of Child Language*, *32*(2), 319–343.

Chwilla, D. J., & Kolk, H. H. J. (2003). Event-related potential and reaction time evidence for inhibition between alternative meanings of ambiguous words. *Brain and Language*, *86*(2), 167–192. doi:10.1016/S0093-934x(02)00527-8

Coutanche, M. N., & Thompson-Schill, S. L. (2014). Fast mapping rapidly integrates information into existing memory networks. *Journal of Experimental Psychology-General*, *143*(6), 2296–2303. doi:10.1037/xge0000020

Davis, M. H., & Gaskell, M. G. (2009). A complementary systems account of word learning: Neural and behavioural evidence. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *364*(1536), 3773–3800. doi:10.1098/rstb.2009.0111

Doherty, M. J. (2004). Children's difficulty in learning homonyms. *Journal of Child Language*, *31*(1), 203–214.

Forster, K. I., & Davis, C. (1984). Repetition priming and frequency attenuation in lexical access. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *10*(4), 680–698.

Gaskell, M. G., & Dumay, N. (2003). Lexical competition and the acquisition of novel words. *Cognition*, *89*(2), 105–132. doi:10.1016/s0010-0277(03)00070-2

Gaskell, M. G., & Ellis, A. W. (2009). Word learning and lexical development across the lifespan. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *364*(1536), 3607–3615. doi:10.1098/rstb.2009.0213

Gernsbacher, M. A. (1984). Resolving 20 years of inconsistent interactions between lexical familiarity and orthography, concreteness, and polysemy. *Journal of Experimental Psychology: General*, *113*(2), 256–281.

Graf Estes, K., Evans, J. L., Alibali, M. W., & Saffran, J. R. (2007). Can infants map meaning to newly segmented words? Statistical segmentation and word learning. *Psychological Science*, *18* (3), 254–260. doi:10.1111/j.1467-9280.2007.01885.x

Graves, W. W., Grabowski, T. J., Mehta, S., & Gordon, J. K. (2007). A neural signature of phonological access: Distinguishing the effects of word frequency from familiarity and length in overt picture naming. *Journal of Cognitive Neuroscience*, *19*(4), 617–631. doi:10.1162/jocn.2007.19.4.617

Hay, J. F., Pelucchi, B., Graf Estes, K., & Saffran, J. R. (2011). Linking sounds to meanings: Infant statistical learning in a natural language. *Cognitive Psychology*, *63*(2), 93–106. doi:10.1016/j.cogpsych.2011.06.002

Joordens, S., & Besner, D. (1994). When banking on meaning is not (yet) money in the bank: Explorations in connectionist modeling. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *20*(5), 1051–1062.

Kawamoto, A. H., Farrar, W. T., & Kello, C. T. (1994). When two meanings are better than one: Modeling the ambiguity advantage using a recurrent distributed network. *Journal of Experimental Psychology: Human Perception and Performance*, *20*(6), 1233–1247.

Landauer, T. K., & Dumais, S. T. (1997). A solution to Plato's problem: The latent semantic analysis theory of acquisition, induction, and representation of knowledge. *Psychological Review*, *104*(2), 211–240. doi:10.1037//0033-295x.104.2.211

Lindsay, S., & Gaskell, M. G. (2013). Lexical integration of novel words without sleep. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *39*(2), 608–622. doi:10.1037/a0029243

Loftus, G. R., & Masson, M. E. J. (1994). Using confidence-intervals in within-subject designs. *Psychonomic Bulletin and Review*, *1*(4), 476–490. doi:10.3758/Bf03210951

Mazzocco, M. M. (1997). Children's interpretations of homonyms: A developmental study. *Journal of Child Language*, *24*(2), 441–467.

McClelland, J. L., McNaughton, B. L., & O'Reilly, R. C. (1995). Why there are complementary learning-systems in the hippocampus and neocortex – insights from the successes and failures of connectionist models of learning and memory. *Psychological Review*, *102*(3), 419–457. doi:10.1037/0033-295x.102.3.419

McMurray, B., Horst, J. S., & Samuelson, L. K. (2012). Word learning emerges from the interaction of online referent selection and slow associative learning. *Psychological Review*, *119*(4), 831–877. doi:10.1037/a0029872

Mestres-Misse, A., Rodriguez-Fornells, A., & Munte, T. F. (2007). Watching the brain during meaning acquisition. *Cerebral Cortex*, *17*(8), 1858–1866. doi:bhl094 [pii]10.1093/cercor/bhl094

Parks, R., Ray, J., & Bland, S. (1998). *Wordsmyth English dictionary – thesaurus*. University of Chicago. Retrieved from http://www.wordsmyth.net

Perfetti, C. (2007). Reading ability: Lexical quality to comprehension. *Scientific Studies of Reading*, *11*(4), 357–383.

Perfetti, C. A., Wlotko, E. W., & Hart, L. A. (2005). Word learning and individual differences in word learning reflected in event-related potentials. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *31*(6), 1281–1292. doi:10.1037/0278-7393.31.6.1281

Qiao, X., & Forster, K. I. (2013). Novel word lexicalization and the prime lexicality effect. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *39*(4), 1064–1074. doi:10.1037/a0030528

Reichle, E. D., & Perfetti, C. A. (2003). Morphology in word identification: A word-experience model that accounts for morpheme frequency effects. *Scientific Studies of Reading*, *7*(3), 219–237. doi:10.1207/S1532799xssr0703_2

Rodd, J., Gaskell, G., & Marslen-Wilson, W. (2002). Making sense of semantic ambiguity: Semantic competition in lexical access. *Journal of Memory and Language*, *46*(2), 245–266. doi:10.1006/jmla.2001.2810

Rodd, J. M., Berriman, R., Landau, M., Lee, T., Ho, C., Gaskell, M. G., & Davis, M. H. (2012). Learning new meanings for old words: Effects of semantic relatedness. *Memory and Cognition*, *40*(7), 1095–1108. doi:10.3758/s13421-012-0209-1

Rugg, M. D. (1990). Event-related brain potentials dissociate repetition effects of high- and low-frequency words. *Memory and Cognition*, *18*(4), 367–379.

Simpson, G. B. (1981). Meaning dominance and semantic context in the processing of lexical ambiguity. *Journal of Verbal Learning and Verbal Behavior*, *20*(1), 120–136.

Storkel, H. L., Armbruster, J., & Hogan, T. P. (2006). Differentiating phonotactic probability and neighborhood density in adult word learning. *Journal of Speech Language and Hearing Research*, *49*(6), 1175–1192. doi:10.1044/1092-4388(2006/085)

Storkel, H. L., & Maekawa, J. (2005). A comparison of homonym and novel word learning: The role of phonotactic probability and word frequency. *Journal of Child Language*, *32*(4), 827–853.

Storkel, H. L., Maekawa, J., & Aschenbrenner, A. J. (2013). The effect of homonymy on learning correctly articulated versus misarticulated words. *Journal of Speech Language and Hearing Research*, *56*(2), 694–707. doi:10.1044/1092-4388(2012/12-0122)

Tamminen, J., & Gaskell, M. G. (2013). Novel word integration in the mental lexicon: Evidence from unmasked and masked semantic priming. *The Quarterly Journal of Experimental Psychology*, *66*(5), 1001–1025. doi:10.1080/17470218.2012.724694

Underwood, B. J. (1957). Interference and forgetting. *Psychological Review*, *64*(1), 49–60.

Underwood, B. J., & Freund, J. S. (1968). Effect of temporal separation of two tasks on proactive inhibition. *Journal of Experimental Psychology*, *78*(1), 50–54.