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

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Abstract

In acquiring word meanings, learners are often confronted by a single word form that is mapped to two or more meanings. For example, long after how to 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, relative to new form-new meaning learning: 1) Form-based familiarity may facilitate learning a new meaning, and 2) meaning-based interference may inhibit learning a new meaning. We examined these two processes by having native English speakers learn new, unrelated meanings for familiar (high frequency) and less familiar (low frequency) English words, as well as for unfamiliar (novel or pseudo-) words. Tracking learning with cued-recall tasks at several points during learning 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 in learning. Following learning, interference from original meanings for familiar words was detected in a semantic relatedness judgment task. Additionally, lexical access to familiar words with new meanings became faster compared to their exposure controls, but no such effect occurred for less familiar words. Overall, the results suggest a biphasic pattern of facilitating and interfering processes: Familiar word forms facilitate learning earlier, while interference from original meanings becomes more influential later. This biphasic pattern reflects the co-activation of new and old meanings during learning, a process that may play a role in lexicalization of new meanings.

Keywords

word learning; word frequency; familiarity; learning efficiency

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 & 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 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.

Conceptualizing learning new meanings as a biphasic interaction of form-meaning connections over time leads to a perspective on lexicalization, 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 lexicalization 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 lexicalization 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 lexicalized 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 lexicalization of novel words. In such learning situations, the co-activation or interaction between new and existing knowledge is enhanced, which may make immediate lexicalization possible.

Although most studies of lexicalization have studied the addition of a new word to the learner's lexicon, Rodd et al. (2012) examined a similar lexicalization 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 lexicalization (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 lexicalization 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 (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 lexicalization 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 lexicalization of new meanings. If new meanings are lexicalized, 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 lexicalization 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 – 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 forty 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 minimize the influence from word neighbors (Storkel, Armbruster, & Hogan, 2006), the trained words had zero or very few orthographic neighbors (69 words had zero neighbor, 9 words had one neighbor each, and 2 words had two neighbors) and word frequency of trained words with neighbors was always higher than their neighbor(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 twenty pronounceable pseudowords (i.e., novel words), which had no word neighbors, 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, twenty-three 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 two 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.

Procedure

As shown in Figure 1, participants first performed a lexical decision task, and then experienced 6 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 6 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 center 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-randomized 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 match any words on the same page.

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 2A. 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 2A). 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 (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 hypothesize 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)

¹The 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 5 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.

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 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 ($F_1(2, 48) = 3.742, p = .031, \eta_p^2 = .135$; $F_2(2, 117) = 3.158, p = .046, \eta_p^2 = .051$): 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 ($F_1(2, 48) = 1.548, p = .223, \eta_p^2 = .061$; $F_2 < 1$).

Lexicalization: Lexical Decision

The data were first analyzed 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 ($F_1(1, 24) = .693, p = .414, \eta_p^2 = .028$; $F_1(1, 78) = 2.977, p = .088, \eta_p^2 = .037$) (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%, $p = .083$; $F_1(1, 24) = 3.000, p = .096, \eta_p^2 = .111$; $F_2(1, 39) = .418, p = .552, \eta_p^2 = .011$); 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 $F_2 < 1, ps > .85$).

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 lexicalization.

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 function of familiarity, even though participants learned the three types of words to similar degrees by the end of the learning phase. We emphasize 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; i.e. 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 minimizes 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.

Lexicalization of New Meanings

Although earlier studies emphasized the importance of offline consolidation on the lexicalization 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. Lexicalization that is strongly driven by the interaction between newly taught knowledge and existing knowledge may not depend on sleep (e.g., Dumay & Gaskell, 2007) 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 lexicalization 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 lexicalization 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 center of which is the co-activation of prior meanings and new meanings. Finally, this co-activation process may be important in the lexicalization of new meanings.

Acknowledgments

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Appendix A. Trained words

Frequency	Word	Frequency	Word	Frequency	Word
high	accident	high	problem	low	mutilate
high	advice	high	realize	low	orifice
high	attorney	high	serious	low	ostracize
high	beautiful	high	silver	low	pervade
high	discuss	high	suppose	low	pundit
high	expect	high	weapon	low	savory
high	explain	low	absolve	low	spastic
high	guilty	low	adroit	low	splotch
high	honest	low	clench	low	squander
high	hospital	low	desiccate	low	stratum
high	imagine	low	epitaph	low	vacillate
high	moment	low	follicle	low	warble
high	obvious	low	frugal	novel	attave
high	opinion	low	harpoon	novel	briment
high	plenty	low	infuse	novel	cobuty
high	president	low	lattice	novel	dumaly
high	several	low	motley	novel	eluseit
high	strange	low	nuptial	novel	flompor
high	survive	low	oblique	novel	hortigen
high	village	low	paragon	novel	imbert
high	afford	low	raucous	novel	lasente
high	assume	low	seclude	novel	nasotel
high	client	low	solstice	novel	opuctoan
high	criminal	low	sporadic	novel	pelitine
high	decision	low	sullen	novel	pordelt
high	famous	low	vertigo	novel	rafkean
high	favorite	low	agitate	novel	riturgish
high	happen	low	apropos	novel	spalent
high	health	low	exodus	novel	spruld
high	kitchen	low	facile	novel	tasdite
high	medical	low	frolic	novel	dromly
high	message	low	garish	novel	vortemt
high	prefer	low	impetus		
high	prepare	low	insignia		

Appendix B. Definitions and probes

Definitions	Probe	Definitions	Probe
oval in shape	round	communicating with gestures	hand
with a rough surface	abrasive	having a tight schedule	busy

Definitions	Probe	Definitions	Probe
full of soup	pot	easy to be cheered up	happier
with many bubbles inside	bubbly	frequently working overtime	job
owned by the government	federal	uncomfortable at others' success	envy
transported by sea	ship	pretending to like someone	fake
having a leathery appearance	leather	extremely anxious	nervous
producing honey	bee	having a large audience	crowd
having a foreign accent	abroad	prone to becoming very cold	freezing
crazy about exercising	gym	living in the deep sea	coral
tending to produce laughter	humorous	scratchy handwriting	illegible
hard to focus on one thing	distracting	sold out rapidly	successful
always wearing a veil	face	with a bowl shape	round
desiring changes	alter	able to become dirty easily	stain
born in an athletic family	sports	causing the growth rate to increase	faster
causing war	conflict	poor in air quality	pollution
caused by flood	damage	bearing petals	flower
marked on the calendar	scheduled	producing wool	sheep
with projecting teeth	mouth	able to avoid predators	prey
able to survive the drought	cactus	causing fever	germ
nine inches long	length	very sensitive to smells	nose
containing diamonds	ring	good at bargaining	trade
able to split in two	divide	staying up late frequently	insomnia
made of coarse cotton fabric	textile	angry because of being cheated	enraged
growing underground	soil	born with a talent for singing	musical
not tasty but nutritious	nourishing	causing movement	move
producing pearls	oyster	of unknown origin	mysterious
causing dental cavities	tooth	appearing in winter	snow
with three horns on head	horned	very similar in color	hue
derived from dead animals	carcass	able to absorb water rapidly	sponge

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Figure 1.
Schematic diagram of the experimental procedure

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).

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).

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).

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).

Table 1

Examples of stimuli in different condition

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

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 (Bryshaert & 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 eighteen raters from Amazon Mechanical Turk as a previous study did (Bryshaert, Warriner, & Kuperman, 2013). Except word frequency and word familiarity ratings, there is no any significant difference across conditions ($ps > .20$).

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).