RUNNING HEAD: FORM AND MEANING IN AFFIX LEARNING

Form and Meaning Influences on the Acquisition of Morphological Endings: Evidence From Learning Artificial Affixes

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Abstract

Knowledge of affixes plays an important role in visual word recognition and word comprehension, but little is known about how this knowledge is acquired. We examined this question by teaching participants novel affixes presented in combination with existing word stems (e.g., sleepnept, buildnept, teachnept). A form-learning condition was compared with a semantic learning condition in which these novel words were given definitions using consistent affix meanings (e.g., the ending –nept refers to agents, such that a sleepnept is 'a participant in a study of the effects of napping'). Tests of recognition memory two days after learning showed that both learning conditions produced good explicit knowledge of the novel words. Participants in both learning conditions also showed evidence of affix knowledge. The results of an offline orthographic segmentation task revealed that participants used knowledge of the novel affixes to segment untrained ambiguous letter strings (e.g., segmenting barnept into bar+nept, rather than barn+ept) irrespective of learning condition. Furthermore, participants in the semantic learning condition were able to generalize their knowledge about the meanings of the novel affixes to choose the correct meaning for stimuli comprising a new stem plus a trained novel affix (e.g., sailnept) in an offline definition selection task. Finally, in a speeded lexical decision task, participants in the semantic learning condition made more false positives for nonwords with novel affixes (e.g., morknept) than for matched nonwords with untrained affixes (e.g., fushnule). Thus following either form or semantic learning, novel affixes are treated as independent orthographic and semantic units in offline tasks. However, evidence for rapid, online-segmentation is only apparent following semantic learning.

Keywords: morphology; language acquisition

Morphologically-complex words constitute a large proportion of words in languages such as English. Composed of more than one morpheme, the majority of these words are formed by combining a stem morpheme (e.g., dark) with an affix (e.g., –ness in, for example, darkness). Affixes play an essential role in linguistic productivity in many of the world's languages, as most affixes occur in many different contexts (e.g., darkness, kindness, oneness) and can combine with novel stems to express new concepts (e.g., aerobicize which means 'to perform aerobics'). It is therefore not surprising that the processing of affixes and affixed words has been examined in considerable detail by psycholinguists.

Research suggests that affixes are represented at both form and semantic levels of processing. The orthographic form of affixes has been shown to play an important role in visual word recognition. Masked priming experiments in which a stem is primed by a morphologically complex word (e.g., departure-DEPART: Rastle, Davis, Marslen-Wilson & Tyler, 2000) have found that the mere presence of an orthographic affix causes decomposition even in cases in which the prime is pseudomorphological (e.g., corner: Longtin, Segui, & Hallé, 2003; Rastle, Davis, & New, 2004) or when the prime is a pseudoword (e.g., habitness: Longtin & Meunier, 2005; McCormick, Rastle, & Davis, in press). This decomposition is automatic, rapid, sublexical, and unaffected by semantics (see Rastle & Davis, 2008, for a review). However, other paradigms show influences of the semantic content of affixes. In long-term priming experiments, for instance, although effects are believed to be caused by early processing, morphological priming is only found for semantically transparent pairs (e.g., teacher-teach: Rueckl & Aicher, 2008). Semantic effects have also been found with paradigms tapping into a later stage of processing. For example, Longtin and Meunier (2007) reported that in long-SOA (cross-modal) priming, interpretable pseudowords like rapidify (i.e. to make rapid) prime their stems whereas non-interpretable combinations like sportation do not. In these cases it is the combined semantic knowledge of the stem and the affix that permits interpretation and therefore supports priming effects.

The studies discussed above contain just a few examples of how previous research has shown that the semantic and orthographic representations of affixes affect word processing in a way that is unique to morphemic units. The question that we wish to address here is: How are these representations of affixes acquired? By definition, morphological affixes never surface in isolation, and so language learners must acquire knowledge of these units from exposure to a number of distinct lexical exemplars, all of which share a common orthographic/phonological ending (or beginning in the case of prefixes). Here we ask what it is that causes people to treat these letter combinations in a different way to other common word endings (e.g., -el in brothel, chapel, etc.) that do not function as affixes.

Studying the Acquisition of Affix Knowledge

One way to examine affix learning in a controlled laboratory setting is by using a word learning paradigm to teach people novel affixes. Word learning has been used effectively to look at the acquisition of phonological (e.g., Gaskell & Dumay, 2003; Davis, di Betta, Macdonald & Gaskell, 2009; Leach & Samuel, 2007; Tamminen & Gaskell, 2008), orthographic (e.g., Bowers, Davis & Hanley, 2005), and semantic (e.g., Clay, Bowers, Davis & Hanley, 2007; Leach & Samuel, 2007; Rueckl & Dror, 1994) representations of new words. Here we demonstrate that these laboratory-based word learning methods can be similarly used to examine the acquisition of morphemic knowledge. Our work goes beyond these previous studies, though, by demonstrating that learners can acquire abstract information about units that never surface in isolation (i.e. affixes that are bound morphemes).

In the present study, a word learning paradigm was used to teach participants novel affixes (e.g., –nept, -ane) in novel word contexts (e.g., sleepnept, kickane). Like real affixes (-er, -ist), these morphemic units never occurred in isolation, only in combination with existing stems. In natural language, affixes modify the meaning and syntactic class of their stems in a variety of ways. Here, we used artificial affixes that enable us to compare purely form-based learning (where participants only receive the orthographic and phonological form of the affix) with a semantic learning condition in which each novel word was given a definition based on a consistent 'meaning' for its morphemic affix. After training participants on these novel words using a simple typing test to be described later (see Bowers, Davis & Hanley, 2005), we assessed morphemic knowledge in a test session two days later. A two-day delay was chosen to ensure that participants had adequate sleep and opportunity for overnight consolidation of the newly-learned affixes (see Davis, di Betta, Macdonald & Gaskell, 2009; Dumay & Gaskell, 2007, for evidence of overnight, sleep-associated consolidation in learning spoken words). We used a series of four different test tasks, aimed at addressing key questions concerning the degree of learning as well as the extent to which novel affixes function like existing affixes. Each task was selected to provide specific insights into the nature of the affix representations acquired by participants.

The first question we wanted to address was whether participants could learn the orthographic form of new affixes in this type of learning paradigm. This question focuses on the most basic aspect of learning: assessing whether participants had learned the letter strings presented during training and their constituent units. Using a forced-choice recognition memory task, we asked not only whether participants could recognize the words they had learned but also whether they could reject complex words containing a trained stem and an untrained affix or words containing an untrained stem and a trained affix (to test affix and stem learning respectively). Furthermore, we tested responses to recombinant pairs, for which learned affixes and learned stems were recombined in novel combinations (e.g., testing on kicknept or sleepane following training with sleepnept and kickane). Additional difficulties in rejecting these recombinant pairs would provide some evidence of morphemic learning since these items are unfamiliar as whole forms. This task also provided a baseline measure of affix learning in case no other morphological effects of learning were found.

Building on this, we then asked whether participants use orthographic knowledge of the trained affixes to segment novel stem-plus-affix combinations. We used an offline segmentation task in which participants were asked to split letter strings into two units. Each test string had two possible stems (e.g., barnept which contains both bar and barn) so that correct segmentation could only be achieved using the orthographic form of the new affix (bar+nept not barn+ept). Test items using word and nonword stems (e.g., sarnept) were used as well as filler items containing existing morphemic affixes (e.g., claimness, suskness). Successfully completing this task requires more than rote, orthographic learning of the trained items. Rather, participants must use the newly learned affixes as units to direct morphological decomposition of the novel complex words. However, even this finding would still fall short of showing that newly-learned affixes have a similar status to true affixes in permitting the rapid, automatic, sublexical segmentation of complex words reviewed above.

A third critical question is therefore whether learned novel affixes would be treated as independent units in online lexical processing tasks such as masked priming (e.g., Rastle, Davis & New, 2004), reading aloud (e.g., Laudanna, Cermele & Caramazza, 1997), and lexical decision (Caramazza, Laudanna & Romani,1988). Here we used a lexical decision task to examine whether the trained novel affixes influence online processing. In this task, only real English words required a ‘yes’ response while the critical stimuli containing the trained novel affixes required ‘no’ responses. Previous research has shown that morphologically-structured nonwords which contain existing affixes are particularly difficult to reject in lexical decision (e.g., clatment - Caramazza, Laudanna & Romani, 1988; Laine, Vainio & Hyönä, 1999; Wurm, 2000). We therefore investigated whether a similar difficulties would be observed for nonwords composed of a nonword stem and a trained novel affix (e.g., morknept for the trained affix -nept) compared to a matched item with an untrained affix (e.g., fushnule for the untrained affix –nule).

Those participants that received semantic training also allowed us to address a final question: can participants generalize learned affix meanings to new stem and affix combinations? Cross-modal priming data reviewed previously suggest that participants can compute the meaning of novel morphemic combinations using existing affixes (e.g., rapidify; Meunier & Longtin, 2007). Here we asked whether participants can be similarly productive in interpreting items with newly-learned affixes by means of a forced choice definition selection task. In this task, participants were presented with learned words (e.g., sleepnept) and with untrained words consisting of an existing stem plus a trained novel affix (e.g., sailnept). For each word, they were asked to choose between two alternative definitions, only one of which was consistent with the learned affix meaning (so if –nept referred to a cost then a consistent meaning for sailnept would be 'The hourly cost of learning how to navigate a yacht' not 'A person who excels in open sea catamaran racing'). This task therefore not only tested rote-learning of definitions for trained novel words, but also tested whether participants can generalize these affix meanings to untrained words. If observed, this would indicate that participants can extract consistent affix meanings without them being explicitly provided during training.

Examining performance on these tasks under form and semantic learning conditions also allowed us to investigate the role of semantics in affix learning and to directly test the theories of morphological learning put forward by Rastle and Davis (2008). Though research suggests that morphological decomposition in early visual word recognition can be insensitive to semantic information (e.g., Rastle et al., 2004), previous research has shown that semantic information is important for the recall (Rueckl & Dror, 1994) and lexicalization (Leach & Samuel, 2007; Tamminen & Gaskell, 2008) of newly learned words (though see also Dumay, Gaskell & Feng, 2004). It is not yet known to what extent semantic knowledge drives the acquisition of formal representations of affixes. While two of the theories advanced by Rastle and Davis (2008) stipulate that formal representations of affixes can be acquired solely on the basis of orthographic / phonological characteristics of affixed stimuli, the third theory that they proposed claims that the acquisition of formal representations of affixes might depend on the provision of semantically-transparent complex forms in which consistent affix meanings combine with the meaning of familiar stems in a predictable, compositional fashion. Thus, only those orthographic endings (or beginnings) that change the meanings of the stems to which they attach in consistent and transparent ways come to function as affix units. On this theory then, we would expect that acquiring formal knowledge of affixes would be impossible in the absence of a semantic component during learning.

Constructing Artificial Affixes

The artificial affixes used in our experiments, were closely modeled after the properties of existing affixes in natural language. We therefore began by considering what factors distinguish true morphemic affixes from other common letter combinations. One of the main indicators denoting that a letter combination is an affix comes from its orthographic context, which provides two significant clues to affix identity. The first of these is the ability to segment complex words into morphemes. If a letter combination is an affix, then one should be able to remove it from the stimulus and be left with other recognizable morphological units (e.g., removing the affix –ment from development leaves the stem morpheme develop). The second contextual clue is that true affixes occur with several different stem morphemes (e.g., the affix –age occurs with numerous stems such as block, drain, post and wreck). These two cues to affix identification provide the basis for the form learning condition in this experiment. Participants were provided with eight novel affixes (e.g., –nept), each of which occurred with eight familiar stem morphemes (e.g., the affix –nept occurred with the stems sleep, build, chop, float, talk, climb, dress and steal). Like existing affixes, the novel affixes never occurred alone and were instead simply provided in context as part of a word learning exercise. Participants were not told that the new words would be affixed and the only indication of morphological structure was that each affix occurred in several different contexts along with familiar stems. Thus in the form learning condition it is only the two contextual cues described above that support the idea that these letter groups were morphological units.

The other main cue present in natural language to ascertaining that a letter string is an affix is semantic. Unlike non-morphological endings, affixes convey meanings through their combination with the meanings of the stems to which they are attached. For example, the word cloudless is a semantically-transparent combination of the stem cloud and the affix –less which means ‘lacking [stem]’. The semantic learning condition in this experiment combined the contextual cues of the form learning condition with an equivalent semantic component. In natural language, however, the meaning of an affixed word is not always clear or unambiguous. While the meanings of many affixed words are clearly related to the meanings of their stems (semantically transparent words – e.g., government), the meanings of others are not (semantically opaque words – e.g., department). Similarly, some affixes have a very consistent meaning (e.g., –ist which usually denotes agency), but other affixes have different meanings in different lexical contexts (e.g., –age which denotes a place in vicarage, an event in breakage, and a charge in postage). In this experiment, however, we opted to use definitions which were both transparent and consistent. Thus, sleepnept would be ‘The hourly rate for taking a nap in an airport bed’ and buildnept would be ‘The extra costs involved in constructing a house on stilts’ with –nept relating to a cost in both cases. However, although all definitions were transparent, the stem was not used in the definitions since repeating the stem in the definition might provide an additional cue to orthographic segmentation.

Method

Participants

Participants in this experiment were 32 native English speakers from Royal Holloway, University of London. Half of these participants were assigned to the form learning condition and half were assigned to the semantic learning condition. Participants all had normal or corrected-to-normal vision, and were free from any known language impairments. They were given £25 (about $36) as compensation for their time.

Materials

Learning Phase. The critical stimuli in the learning phase of the experiment were nonwords consisting of an existing stem and a novel affix.

Sixteen novel affixes were created from existing word endings, none of which were words in their own right. The novel affixes were selected on the basis of four structural types (CVCV, VCV, CVCC, and VCC), and four vowels (A, E, U, and O). Of the novel affixes, eight were learned by participants in Group A and the other eight were learned by participants in Group B. Those novel affixes learned by Group A were used as untrained control affixes in the test tasks for Group B and vice versa. In this way, trained and untrained novel affixes were counterbalanced between participant groups. Table 1 contains the novel affixes with the ‘A’ and ‘B’ labels showing how they were divided between participant groups.

Insert Table 1 here

Each novel affix was paired with eight existing word stems, which were shared across participant groups (e.g., so that the stem sleep occurred with the affix –nule for participants in Group A and with the affix –nept for participants in Group B), thus creating 64 novel words for each participant to learn. Stems were monosyllabic monomorphemic content words between three and five letters in length. Half of the novel affixes used in each participant group were paired with noun stems and half were paired with verb stems.

Audio files were created for each of the novel words. These were recorded by a female native English speaker and were edited to a consistent duration of 1500 ms.

Definitions were then created for each novel word for use in the semantic learning condition. These definitions were formulated by combining a consistent affix definition with a semantic reference to the stem. In order to ensure that the definitions themselves did not act as a segmentation cue, none of the stems were actually used in the definitions, and each novel word was provided with two definitions which were counterbalanced between participant groups[1] to mitigate the possibility that some definitions were easier to learn than others. Table 2 lists the affix meaning types as well as an example of each type worked into a definition. These definition types were based on affix meanings that occur in English including a place (e.g., –ery in bakery, nunnery), a tool (e.g., –er in cooker, eraser), a person (e.g., –ist in cyclist, racist), and a cost (e.g., -age in postage, corkage).

Insert Table 2 here

Definition length was controlled for the number of words (9-11) and syllables (13-17) in the definition. For the learning phase, all definitions were recorded by the same female native English speaker who recorded the novel words. The audio files of the definitions were then cut to leave a 300ms gap before the start of the definition and a minimum of 300ms after the speaker had stopped. The final sound files lasted between 3500ms and 4500ms.

Test Phase. The test phase of the experiment consisted of a recognition memory task, an offline segmentation task, a lexical decision task, and a definition selection task. The trained and untrained novel affixes used in these tasks were the same as those selected for the learning phase of the experiment and the stems were monosyllabic monomorphemic content words between three and six letters in length. No stems were repeated across tasks.

(a) Recognition Memory. The stimuli for the recognition memory task consisted of all 64 learned words (e.g., sleepnept) as 'yes' responses and three different types of 'no' responses. The 'no' response stimuli included 32 trained stem + untrained novel affix items (four trained stems for each of eight untrained novel affixes, e.g., sleeptege), 32 untrained stem + trained novel affix items (four untrained stems for each of eight trained novel affixes, e.g., fruitnept), and 64 recombinant pairs consisting of trained stem + trained novel affix combinations which did not occur during training (eight stems for each of eight trained novel affixes, e.g., sleephoke).

(b) Offline Segmentation. The critical stimuli in the offline segmentation task were 160 nonwords that paired ten word stems and ten nonword stems with each of the eight trained novel affixes for each participant group. The word stems used all had N, T, L, or H as their final letter which could be removed to produce an embedded word (e.g., removing the N from barn produces bar). Each stem was paired with two novel affixes, one of which shared the final letter of the stem (e.g., –nept in barnept) and the other did not (e.g., –ort in barnort). For example, participants in Group B saw both barnept and barnort (having learned the novel affixes –nept and –ort). This design enabled us to test whether participants would treat the same stem differently according to the novel affix that they had learned (e.g., by segmenting barnept as bar+nept, and by segmenting barnort as barn+ort), thereby also controlling for other possible effects of the stems used. Stimuli using nonword stems were constructed similarly (e.g., using stimuli like sarnept and sarnort).

In addition to the critical stimuli, we included 160 filler nonwords that paired ten word stems and ten nonword stems with each of eight existing affixes. The existing affixes used were individually matched on length to the trained and untrained novel affixes and consisted of the same type of consonant-vowel combinations. They formed two stimulus types: untrained stem + existing affix in an ungrammatical combination (e.g., claimness) and nonword stem + existing affix (e.g., suskness).

(c) Lexical Decision. The stimuli for this task consisted of 288 letter strings: 144 familiar words (i.e. real English words) for which a 'yes' response was expected, and 144 nonwords for a 'no' response (no trained novel words were used). The critical stimuli in this task are the 'no' responses which were of three different types: nonword stem + trained novel affix (e.g., morknept), nonword stem + untrained novel affix (e.g., fushnule), and nonword stem + existing affix (e.g., clatment). The existing affixes used were individually matched on length to the trained and untrained novel affixes and were the same as those used in the offline segmentation task. The nonword stems were selected from the English Lexicon Project website (Balota et al., 2002) and were between three and five letters in length, had between 10 and 20 orthographic neighbors, and had a positional bigram frequency between 500 and 1500. They were also matched across conditions on these three factors. Each type of 'no' response contained 48 items (six stems for each of the eight affixes of each type), and both participant groups saw exactly the same stimuli (with the stimuli counting as nonword stem + trained novel affix in for Group A, counting as nonword stem + untrained novel affix for Group B and vice versa).

The lexical decision 'yes' responses were real English words which were the same across participant groups and consisted of two different types (with 72 words in each): existing complex words (e.g., duckling) and non-compound bisyllabic words containing embedded monosyllabic words (e.g., kidney which contains the embedded word kid). For the existing complex words, 12 existing affixes were selected of which six were three letters in length and started with a vowel, and six were four letters in length and started with a consonant, thus matching the existing affixes in length distribution and type of starting letter to the trained and untrained novel affixes. Each affix again occurred with six different stems. Across 'yes' and 'no' responses, the lexical decision stimuli were matched on average word length.

(d) Definition Selection. The definition selection task consisted of forced-choice judgments about the meanings of 128 novel words. Sixty-four of these were words presented during the learning phase, and 64 paired the learned novel affixes with untrained word stems. These untrained word stems had not been used previously and followed the verb or noun preference of each novel affix established in the learning phase.

For the novel words presented during the learning phase, participants were forced to choose between the two definitions that had been created for those novel words (and which had been counterbalanced across participants, see footnote 1). For the untrained novel words, two definitions were created for each stimulus. These definitions were based on the same two definitions for each affix as those employed in the learning phase, so that a definition consistent with each affix meaning for each semantic learning group was created. In this way, the same stimuli could be shown to both participant groups, with the counterbalancing condition dictating which of the two definitions formed the correct response.

Procedure

The experiment took place on two separate days with one non-experiment day in between to allow time for consolidation. Day 1 was assigned to the learning phase, while all the test tasks were carried out on Day 3. On Day 3, participants first performed the lexical decision task, followed by the offline segmentation task and the recognition memory task. This order was chosen to minimize the influence of additional learning during the administration of the test tasks. For the participants in the semantic learning condition, the definition selection task was added at the end of the test session.

All parts of the experiment, except for the offline segmentation task, were performed individually on a computer, with responses being made on either the keyboard (for the learning phase) or a button box (for the test tasks). Stimulus presentation and data recording were controlled by the DMDX software (Forster & Forster, 2003). The learning phase presented on Day 1 lasted around an hour for participants in the form learning condition and around two hours for participants in the semantic learning condition due to the greater duration of the auditory presentation of the definitions. The task phase on Day 3 lasted between 45 and 60 minutes depending on whether it included the definition selection task.

Learning Phase. On any given trial, participants in the form learning condition would see a novel word on the screen (in lowercase) in white letters on a black background. This word would be on the screen for 43ms before the audio file of the word started and would remain on the screen for the 1500ms of the audio file. The screen would then go blank at which point participants were instructed to type the word they just saw. Pressing the enter key would then take the participant to the next word.

For participants in the semantic learning condition, after participants had typed the novel word, the participant would hear the audio file of the definition of the word. Pressing enter would then take them to the next word.

The learning phase consisted of 12 cycles of all 64 words so that each item was seen 12 times and each affix was seen 96 times (768 exposures in total). The order of the items was randomized in each cycle.

Test Phase.

(a) Recognition Memory. During the recognition memory task, a fixation cross (+) would appear on the screen followed by the letter string (in lowercase) which would remain on the screen until the participant responded. Participants were asked to respond to whether each item was one of the words they had learned during the learning phase of the experiment. No practice items were given.

(b) Offline Segmentation. The stimuli for the offline segmentation task were presented in booklet form. The participants were asked to split each letter string into two units by drawing a line through the letter string with a pen as shown in an example. They were asked to go through the letter strings in the order in which they were presented and to cover their answers as they went through. They were not allowed to look back at earlier answers or to change them. Each participant received the letter strings in a different random order.

(c) Lexical Decision. For the lexical decision task, participants were instructed to indicate with a speeded button press whether each letter string was a real English word or not. Participants were asked to respond as quickly and as accurately as possible. Each letter string (in lowercase) appeared on the screen following a fixation cross (+), and remained on the screen until the participant responded. Participants were given eight practice trials prior to starting the main experiment.

(d) Definition Selection. During the definition selection task, each stimulus with its two possible definitions was shown on the screen until the participant responded by picking one of the definitions. Participants were told to select the definition they had learned for the trained novel words and the definition they thought was the most suitable for the untrained novel words.

Results

Data from all participants and tasks were included in the analyses which were primarily performed using mixed effects models (Baayen, 2008). Logit analyses were performed for categorical data in the segmentation and definition selection tasks, and for errors in lexical decisions (Jaeger, 2008). Linear mixed effects analyses were used for lexical decision response times. Recognition memory data was subject to signal detection analysis (see Snodgrass & Corwin, 1988).

Recognition Memory. In order to correct for any response biases in this task, we computed hit and false-alarm rates for each test condition to derive signal detection measures of recognition memory performance (d-prime). We computed a measure of successful stem recognition by calculating the difference between the percentage of correct responses (hits) to learned items (indicating a correct recognition of the learned stem) and the percentage of incorrect ‘yes’ responses (false alarms) to items with untrained stems (indicating an inability to correctly reject untrained stems). Measures of affix recognition (comparing correct ‘yes’ responses with ‘yes’ responses to items with untrained affixes) and whole word knowledge (comparing correct ‘yes’ responses with ‘yes’ responses to recombinant pairs) can be calculated in the same way. Average d-prime values are shown in Table 3. Since d-prime values can only be computed by combining information across different items (i.e. hits and false-alarms), we used conventional repeated measures ANOVAs by participants in analyzing these data as well as one-sample t-tests (comparing d-prime values to zero to test for above chance performance in each condition).

Insert Table 3 here

An ANOVA was performed on the d-primes with learning type (form or semantic) as the between-participant variable and knowledge type (affix, stem, or whole word) as the within-participant variable. No significant interaction was found ($F(2,60) = 2.24$, $MS = .24$, $p > .1$) While the ANOVA showed no main effect of learning type ($F(1,30) = .22$, $MS = .30$, $p > .6$), there was a main effect of knowledge type ($F(2,60) = 158.31$, $MS = 17.21$, $p < .001$). Post-hoc comparisons revealed that affix recognition was better than stem recognition ($t(31) = 3.75$, $p < .01$) and that whole word knowledge was significantly worse than both affix recognition and stem recognition (compared to stem recognition: $t(31) = 16.79$, $p < .001$; compared to affix recognition: $t(31) = 13.97$, $p < .001$). This indicates that participants had particular difficulty rejecting recombinant pairs. The ANOVA also showed a significant intercept, indicating that overall performance was better than chance ($F(1,30) = 247.74$, $MS = 337.50$, $p < .001$). Indeed, post-hoc analyses of the individual d-prime measures showed that participants performed better than chance after both form and semantic learning for each type of knowledge (all $p < .001$).

Offline Segmentation. In the offline segmentation task, participants were asked to split letter strings into two units and performance was measured by the number of letter strings that were segmented so that the affix (trained or existing) formed one of the units. Participants performed well for letter strings containing existing affixes, with an overall average performance of over 93% correct (though it is worth keeping in mind that segmentation of these items was unambiguous since only one stem was present; e.g., claimness).

Mixed effects logit models were used to examine the number of correct segmentations for the letter strings containing trained novel affixes. First, we examined the interaction between learning type (form/semantic) and stem type (word/nonword) as fixed factors with participants and items as random factors. No significant effects of learning type or stem type were found in this analysis, and there was no evidence for an interaction between these factors (all $z < 1$).

Our key question, however, was whether training influenced participants' segmentation performance. Unfortunately, answering this question is complicated by a number of factors. One problem is that it is difficult to decide a-priori what chance performance on this task is. Although the task was based on stimuli that contain two possible stems for word stem items (e.g., barn and bar), each letter string actually contains 5-8 possible responses (with an average of 6.5) and so random segmentations would be correct for 15.4% of trials. Moreover, even if we consider chance performance to be 50% (reflecting the fact that there were two possible stems in each stimulus), several other factors besides training also influenced segmentation performance. Linear mixed effects analyses examining these factors as fixed effects (with only participants and items as random factors) show that segmentation performance was affected by a preference for the stem with the higher final positional bigram frequency as calculated by the ratio of the positional bigram frequencies for the final bigrams of the two possible stems (e.g., ar for bar and rn for barn: $z = 8.88$, $p < .001$). It was also affected by a preference for longer stems ($z = 7.43$, $p < .001$), and whether the stem had already occurred (performance being better at the first occurrence of the stem: $z = 3.67$, $p < .001$). Segmentation performance for items with word stems was additionally affected by a preference for the more frequent stem as calculated by the ratio of the frequencies of the two possible stems (e.g., bar and barn: $z = 2.26$, $p < .05$).

Despite these unforeseen effects, a logit mixed effects analysis looking at the overall number of correct segmentation responses (without any fixed effects) showed that participants selected the learned affix as one of the units significantly more than 50% of the time ($z = 3.85$, $p < .001$). These results suggest that participants segmented the ambiguous letter strings according to the affix they learned after both form and semantic learning independently of whether the stem was a word or a nonword. Table 4 shows the overall percentage of correct responses found for trained novel affixes in the offline segmentation task.

Insert Table 4 here

Lexical Decision. Table 5 shows the mean reaction times (trimmed at 2000ms) and the error rates (%) for the 'no' responses across learning types. The 'yes' responses in this task reflected performance on filler stimuli so were not analyzed.

Insert Table 5 here

Consistent with the existing literature (e.g., Caramazza, Laudanna & Romani, 1988), significant inhibition of lexical decision responses was observed for nonwords containing pre-existing affixes (e.g., clatment) for participants in both the form and semantic learning conditions. Mixed effects models with affix type (existing affix/untrained novel affix) as fixed factor and participants and items as random factors showed that nonwords containing existing affixes were responded to more slowly and with more errors than nonwords containing untrained novel affixes (errors: $z = 5.42$, $p < .001$; reaction times: $t = 4.72$, $p < .001$).

For the nonwords that did not contain pre-existing affixes, we examined lexical decision performance using a mixed effects model that included learning type (form/semantic) and affix type (trained novel affix/untrained novel affix) and their interaction as fixed factors and participants and items as random factors. Results showed an interaction between learning type and affix type on error rates ($z = 2.58$, $p < .01$). This interaction reflected the fact that items with trained novel affixes yielded more errors than items with untrained novel affixes after semantic learning ($z = 3.55$, $p < .001$) but not after form learning ($z < 1$). A similar mixed effects model was used to examine the response time data but no interaction or effects of affix type were found.

Definition Selection. Data from the definition selection task showed that participants in the semantic learning condition had learned the definitions given for the learned novel words well, with performance averaging 94.1% correct and with all participants scoring over 80% correct. Unsurprisingly, a mixed effects logit model of responses to learned novel words (containing no fixed factors and participants and items as random factors) showed that participants performed better than chance on these items ($z = 13.48$, $p < .001$).

What is more remarkable, however, was that the same result was found for novel words consisting of an untrained stem and a trained novel affix (e.g., sailnept). Participants showed an impressive ability to generalize affix definitions to these words, selecting the correct definition for 72% of trials. This was significantly better than chance performance in a similar mixed effects logit model ($z = 4.1$, $p < .001$).

Discussion

This study provides the first demonstration of affix learning in a laboratory setting. Our experiment compared the impact of form and semantic training on the acquisition of novel affixes using a lexical decision task, an offline segmentation task, a recognition memory task, and a definition selection task.

Data from the recognition memory task showed that a single, form-based learning session was sufficient to promote good explicit knowledge of words containing novel affixes. Correct rejections for words containing an unlearned stem or an unlearned affix was also high. However, participants had difficulty rejecting items containing two learned units incorrectly combined. This difficulty in rejecting recombinant pairs provides an initial indication that participants treated these novel items as containing sublexical units: participants that rote-learned novel words as whole forms would not have shown this difficulty. Recognition memory data following semantic learning showed essentially the same pattern as after form learning. Hence, there is no indication from these results that explicit knowledge of novel words and affixes is enhanced by the provision of semantic information.

Results from the offline segmentation task showed that participants in both training conditions segmented ambiguous letter strings according to the newly learned affixes. Participants split letter strings like barnept or barnort at the morphological boundary (after bar or barn) based on the affix that they had learned. This effect occurred equivalently for test items in which the stem was a word or a nonword as well as for semantic or form-only learning. This finding shows that affix learning influences how participants segment letter strings, and provides further evidence of the status of affixes as independent orthographic units. Moreover, the fact that this effect was obtained as a consequence of purely form-based learning shows that participants treat affixes as orthographic units even when they have not been provided with any form of explicit morphological information and do not know the meanings of these units. Orthographic segmentation of morpheme-like units can arise solely from presentation of novel affixes in the context of a variety of familiar lexical stems. This finding shows that semantic information is not necessary for acquiring knowledge of sublexical units, and that segmentation can occur on the basis of formal representations alone. The implications of this finding for accounts of affix learning will be discussed subsequently.

Results from the lexical decision task go beyond this in showing an effect of affix learning in an online task, thereby implicating a more rapid segmentation process for newly learned affixes. However, while effects for existing affixes were consistently replicated, the inhibitory effect for nonwords containing a learned affix was only observed in the semantic learning condition. No effect was found for trained novel affixes in the form learning condition. Since there was a significant interaction between affix type (trained/untrained) and learning condition (form/semantic) in the error data, this suggests that incorporating semantics during learning was critical for our finding an effect of learning in an online task.

Lastly, results of the definition selection task showed that participants not only learned the definitions well but were also able to extract affix meanings from these definitions and use them to understand untrained novel words. This result indicates that participants can treat these novel affixes not only as independent orthographic units but also as semantic units that modify the meanings of familiar stems in consistent ways. These results show that participants used novel affixes productively and were able to compute a plausible meaning for a stem plus learned affix combination that was not presented during training. That is, participants treat our newly-learned affixes in the same way as participants treat the real affix –ify in accessing the meaning of a novel word like rapidify.

Our findings propose an interesting dilemma for the role of semantics in orthographic affix learning. While equivalent learning effects were found for form and semantic learning in the offline segmentation task, only semantic learning showed an effect of learning in the lexical decision task. The first of these findings suggests that a semantic component is not necessary for orthographic affix learning, arguing against the strictest interpretation of the third theory of affix acquisition proposed by Rastle and Davis (2008). However, the second finding indicates that semantics may play a role in orthographic affix learning to the extent that this enables online effects in the lexical decision task. Previous research in novel word learning has been suggested that a semantic component during learning may be essential for the lexicalization of novel words, which is, in turn, essential for finding online effects (e.g., Leach & Samuel, 2007; McKay et al., 2008; Tamminen & Gaskell, 2008). Semantics might be playing a similar role here. Alternatively, although our offline segmentation task data indicate that form-meaning regularities are not crucial for orthographic affix learning, such regularities may still play a role in the acquisition of orthographic affix knowledge which could allow the rapid, automatic orthographic segmentation necessary for online effects.

It is also interesting to consider the role of phonology in affix learning. In this experiment, both form learning and semantic learning included an auditory presentation of the novel words with an unstressed pronunciation of the affix. Since previous word learning experiments have shown that the presentation of phonology strengthens the orthographic representations of novel words (e.g., McKague, Davis, Pratt & Johnston, 2008), it is not unlikely that it aided affix learning in this experiment. The importance of phonology for affix learning should therefore be further examined.

The finding that participants can generalize learned affix meanings to new-stem plus learned-affix combinations with considerable accuracy goes beyond existing data on semantic effects in word learning paradigms. Since the definitions used during learning did not include the stem, affixes were never presented in isolation, and participants were not told about the presence of affixes or their meanings, this finding seems to indicate an impressive degree of implicit, linguistic abstraction. This form of generalization appears sufficient to warrant the claim that these affix units were being used productively by participants despite only a few hours of training in a limited set of lexical and semantic contexts. Future research using this method will be important in exploring factors that influence this form of abstraction.

To summarize, this study has shown that after simple form and semantic learning, novel affixes are treated as independent orthographic and semantic units in offline tasks. Moreover, there was also evidence for rapid, online segmentation of these novel affixes, although this was limited to those participants that received semantic learning. Such findings are striking given that the artificial affixes learned by participants in the present study only surfaced in a small number of items, and like real affixes never occurred in isolation.

Our work provides the first demonstration of using an artificial learning paradigm to investigate the acquisition of the form and meaning of novel, affix-like units. This method provides an empirical foundation for future studies in which the form and meaning of learned affixes are manipulated so as to provide a unique source of information on the nature of form-based and semantic representations of morphemic units. We anticipate that, as for other domains of language (e.g., spoken words - Gaskell & Dumay, 2003; speech segmentation - Saffran, Newport & Aslin, 1996), significant theoretical progress can be made by studies using these artificial analogs of natural language.

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Footnotes

[1] This counterbalancing was separate from the counterbalancing of the affixes so that Group A1 and Group B1 saw the same definition (definition 1) for sleepnule or sleepnept respectively while Groups A2 and B2 saw definition 2 for sleepnule or sleepnept.

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Table 1: The novel affixes labeled by group.

CVCV		VCV		CVCC		VCC	
labe	B	ane	A	halk	A	aph	B
hoke	B	ose	A	lomb	A	ort	B
nule	A	ude	B	tund	B	uck	A
tege	A	ete	B	nept	B	esh	A

Table 2: The definition types and example definitions used during semantic learning.

Stem	Type	Example Word	Example Definition
verb	place	kickort	A large field used by footballers to practice penalties
noun	place	cointund	The factory in which the twenty pence piece is produced
verb	tool	pourlabe	A bottle cap used for decanting exact measures of a liquor
noun	tool	wheathoke	A harvesting tool used by farmers in the middle ages
verb	person	sleepnept	A participant in a study about the effects of napping
noun	person	rugete	A person who imports and sells handmade Indian carpets
verb	cost	leapesh	The cost of having a stuntman jump out of a building
noun	cost	bombaph	The cost of buying enough explosives to blow up a car

Table 3: Recognition Memory – d-prime measure of stem, affix, and whole word knowledge.

Item Type	Form Learning	Semantic Learning
Stem Knowledge	1.98	2.25
Affix Knowledge	2.50	2.42
Whole Word Knowledge	0.98	1.13

Table 4: Offline Segmentation – The percentage of responses in which participants segmented stimuli according to the affixes learned.

Stem Type	Example	Form Learning	Semantic Learning
Word Stems	barnept	55.7	57.6
Nonword Stems	sarnept	56.9	56.1

Table 5: Lexical Decision – The mean RTs and % errors (ER) of the 'no' responses.

		Form Learning		Semantic Learning	
Item Type	Example	RT	ER	RT	ER
Nonword Stem + Trained Novel Affix	morknept	659.8	0.8	727.5	4.7
Nonword Stem + Untrained Novel Affix	fushnule	660.4	1.5	721.0	1.4
Nonword Stem + Existing Affix	clatment	718.6	4.6	769.6	5.9