

Article

Adult Word Learning as a Function of Neighborhood Density

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Received: 28 November 2017; Accepted: 22 February 2018; Published: 6 March 2018

Abstract: Previous studies exploring the influence of neighborhood density (ND) during adult word learning have largely relied on tasks designed for young, preliterate children. In order to examine effects of ND on adult word learning during an ecologically valid task, eight nonwords varying in neighborhood density (4 dense, 4 sparse) were taught to 50 typical adults in the context of a lecture. Half of the participants ($n = 25$) were solely exposed to the phonological forms of the nonwords, while the other half of the participants ($n = 25$) were exposed to both the phonological forms and orthographic representations. Results indicated that participants who only heard the nonwords learned more dense words than sparse words, similar to prior work. However, participants who heard as well as saw the nonwords learned dense words and sparse words to a similar degree, in addition to overall greater learning of sparse words. Thus, learning of sparse words can improve when orthographic information supplements the phonological information. An account of working memory is re-visited to interpret the results related to auditory and visual processing during lexical acquisition.

Keywords: word learning; neighborhood density; adults; phonology

1. Introduction

While the majority of word learning studies have been conducted with children in various stages of language development, fewer have examined how adults incorporate new words into their lexicon. Yet, adults continue to increase their vocabulary throughout the lifespan, such as learning jargon in their selected field of study or acquiring novel words in response to societal changes (e.g., *selfie*, *unfriend*). Some of the cognitive processes utilized during word learning may be similar regardless of age, such as the activation of phonological working memory upon exposure to a novel auditory form (Adams and Gathercole 2000; Gathercole and Baddeley 1990). Still, other word learning processes may depend on age-related skills acquired during the course of development. For example, reading and writing are mastered much later than when a child's first words are produced. In the word learning literature, a variety of lexical and sublexical factors have been explored to discern what may aid or hinder word learning in children and, to a much lesser extent, in adults. Three of the most frequently investigated variables include word frequency (WF; how often a word occurs in a language), phonotactic probability (PP; the probability of sounds occurring and co-occurring), and neighborhood density (ND; an index of how similar one word sounds to others in the lexicon). It is this last variable that remains the focus of the current study.

Neighborhood density has been operationalized in the literature as the number of similar-sounding forms, dubbed *neighbors*, that can be created by substituting, adding, or deleting a single phoneme (Landauer and Streeter 1973; Luce and Pisoni 1998; Freedman et al. 2016). Hence, neighbors for the word *bat* include *mat* (a substitution), *at* (a deletion), and *brat* (an addition). Words with many neighbors are designated as *dense*, while words with few neighbors are termed *sparse*. ND has typically been co-investigated with PP during word learning studies to differentiate their individual

influences (e.g., [Storkel et al. 2006](#)). This is potentially problematic, given their positive correlation (i.e., words with more probable sounds and sequences tend to be from dense neighborhoods). It is therefore important that in order to isolate true effects of ND on word learning, stimuli must be properly controlled for a number of variables, particularly PP.

1.1. Background Literature

1.1.1. Neighborhood Density and Known Words

The influence of ND on the recognition of known words in the lexicon has been extensively studied. An inhibitory effect of ND has repeatedly been found, namely that sparse words are perceived more quickly and accurately than dense words ([Chan and Vitevitch 2015](#); [Helfera and Jesse 2015](#); [Luce and Pisoni 1998](#); [Taler et al. 2010](#); [Vitevitch and Luce 1998, 1999](#)). This has typically been attributed to an account of lexical competition ([Luce and Pisoni 1998](#); [Vitevitch and Luce 1998, 1999](#)). Under the assumption that words compete with one another for selection during language processing, words with a large set of neighbors may be subject to greater competition than those with few neighbors. This increased lexical competition can lead to slower and less accurate perception of dense words compared to sparse words, both in clean and noisy listening conditions ([Luce and Pisoni 1998](#); [Vitevitch and Luce 1998, 1999](#)). Note that while a facilitative effect of ND has been found during tasks of elicited speech production (e.g., spoonerisms, tongue twisters), these tasks significantly differ from those employed in the present study. The reader is referred to [Vitevitch and Luce \(2016\)](#) for a summary of facilitative effects of ND during speech production.

1.1.2. Neighborhood Density and Novel Words

In addition to examining effects of ND on the recognition of known words, one of the earliest studies to determine the influence of ND on novel word learning in adults was conducted by Storkel and colleagues ([Storkel et al. 2006](#)). In the study, novel visual objects were paired with nonwords varying both in ND and PP, and were presented in a narrative context originally designed for preschool children ([Storkel 2004](#)). The pictures were selected from children's books, and the semantic categories used for the adult participants were identical to those taught to children: candy machines, toys, horns, and pets. A picture-naming task was administered after one, four, and seven exposures to measure word learning. Findings revealed that adults learned dense words to a greater degree than sparse nonwords. However, when response accuracy was analyzed based on degree of accuracy (partially correct vs. completely correct), no difference was found between dense and sparse words on partially correct responses. The only observed influence of ND was on completely correct productions, with accuracy on dense words surpassing that of sparse words. The authors accounted for these findings by proposing a word-learning model related to working memory and phonological overlap. First, they argued that dense nonwords have longer activation periods in working memory due to increased activation from real-word neighbors held in long-term memory ([Roodenrys and Hinton 2002](#)). These real-word neighbors purportedly strengthen the 'memory trace' of dense nonwords in working memory, facilitating a new lexical entry more quickly than a sparse nonword. Second, they theorized that the integration and stabilization of a new lexical entry may be influenced by ND. Specifically, spreading activation between the lexical and phonological representations of nonwords and their real-word neighbors can facilitate word learning. Dense nonwords will activate more existing lexical and phonological representations than sparse nonwords relative to the number of real-word neighbors. As such, representations of novel words that phonologically resemble many existing words in the lexicon (i.e., dense) may be integrated and stabilized to a greater degree than those that do not (i.e., sparse). This would result in quicker learning of dense nonwords rather than sparse nonwords. Support for this possibility was found during simulations in an artificial network ([Vitevitch and Storkel 2013](#)).

In another adult word learning study exploring the role of ND, [Stamer and Vitevitch \(2012\)](#) taught real words in a second language (Spanish) that participants were in the process of acquiring. Unlike the

design in [Storkel et al. \(2006\)](#), which paired nonwords with novel visual objects, [Stamer and Vitevitch \(2012\)](#) used pictures of real objects that would be familiar to participants (e.g., a bucket). The Spanish words that were paired with real objects varied in their ND. Results indicated that participants learned more dense words than sparse words as measured via a picture-naming task, referent identification task, and perceptual identification task. [Stamer and Vitevitch \(2012\)](#) invoked the same word-learning model previously discussed ([Storkel et al. 2006](#)) to explain their findings.

Finally, in a study more similar to [Storkel et al. \(2006\)](#), [Freedman \(2015\)](#) paired nonwords varying in ND with novel visual objects. The object pairings were then embedded into a child-friendly narrative. In contrast to the aforementioned studies, the task was administered to both preschool children and adult participants in order to explore potential interactions of ND and age. Learning was measured via a picture-naming and referent identification task after one, four, and seven exposures. Results showed that children learned sparse words to a greater degree than dense words, suggesting an inhibitory effect of ND rather than a facilitative effect; adults learned dense and sparse words to a similar degree. That is, no effect of ND was found on adult word learning. Possible explanations for the observed developmental difference included considerations of vocabulary size (i.e., lexical competition in small versus large lexicons), working memory capacity, and conscious word learning strategies such as mnemonic devices. Differences in results compared to [Storkel et al. \(2006\)](#) were attributed to stimuli control and ease of the task. For example, while PP and ND were orthogonally varied in [Storkel et al. \(2006\)](#), PP was matched between ND conditions in [Freedman \(2015\)](#). This is relevant given that [Storkel et al. \(2006\)](#) only found facilitative effects of ND when dense nonwords were also high in PP; ND may not be a robust variable on its own during adult word learning. Regarding ease of the task, adult participants in [Storkel et al. \(2006\)](#) were asked to learn 16 nonwords, while adult participants in [Freedman \(2015\)](#) were asked to learn eight nonwords; this simplification was necessary to avoid potential floor effects in the study's younger participants.

1.1.3. Orthography and Novel Words

The presence or absence of orthography has previously been shown to influence language processing during adult word learning. [Rastle, McCormick, Bayliss, and Davis \(Rastle et al. 2011\)](#) paired nonwords with novel black and white line drawings; semantic information was not provided about the objects. In the first part of the experiment, participants solely heard the nonwords; on the next day, participants were exposed to either regular or irregular orthographic forms of the stimuli. Findings revealed that after participants were exposed to the orthographic forms of the nonwords, reaction times increased for nonwords with regular orthographic forms compared to those with irregular orthographic forms. This result was observed during two tasks: picture naming and lexical decision. Of note, neither of these tasks required orthographic processing, yet effects of orthography still occurred. In order to explain the findings, the authors concluded that orthographic representations might be automatically activated during speech processing. Furthermore, they proposed that there is 'massive interactivity' involved in language processing that allows for bidirectional activation of orthographic and phonological representations.

In another word learning task with adults, [Saletta, Goffman, and Brentari \(Saletta et al. 2016a\)](#) paired nonwords with novel visual objects (i.e., make-believe aliens); no other semantic information was provided. In the experiment, participants solely heard some of the nonwords; in another condition, the same participants read a different set of nonwords aloud. Results indicated that participants produced nonwords in the orthographic condition more accurately following the experiment than prior to the experiment; production accuracy notably did not improve for nonwords in the phonological condition. [Saletta et al. \(2016\)](#) proposed that participants were able to successfully integrate novel words' orthographies into newly-formed lexical representations. This integration subsequently facilitated productions of these novel words relative to those presented without their orthographic forms.

Lastly, in a follow-up study, Saletta, Goffman, and Hogan (Saletta et al. 2016b) administered a similar task to that described above to three groups of participants: school-aged children, adults with typical reading proficiency, and adults with low reading proficiency. During the task, participants were exposed to either phonological or orthographic forms of the nonwords. Despite differences in age and literacy skills, all three groups only improved in their productions of the nonwords presented with their orthographic forms. The authors suggested that orthography interacts with speech production during word learning, proposing that participants in the study may have intentionally used orthography as a mnemonic device to support phonological learning.

1.2. The Present Study

Despite several experiments designed to determine effects of ND as well as orthography on adult word learning, most studies have arguably lacked ecological validity. Adults do not typically acquire words through an isolated exposure to a novel phonological form and single object (e.g., 'This is a ____'), but rather in the ongoing context of related information. This is particularly true for college students, who are routinely challenged to expand their lexicon depending on their chosen field of study (e.g., psychology, physics). Additionally, Marzilli, Delello, Marmion, and McWhorter (Marzilli et al. 2015) reported that nearly 80% of college students learn information in the classroom through the use of Microsoft PowerPoint. And yet, previous studies of this nature have relied on either teaching adults simple pairings of nonwords and objects (Rastle et al. 2011; Saletta et al. 2016a; Storkel et al. 2014; Vitevitch et al. 2014), or using a narrative created for young, preliterate children (Freedman 2015; Han et al. 2016; Storkel et al. 2006). In order to more validly assess how ND impacts adult word learning, if at all, a task must first be created to mirror a typical learning experience. Otherwise, adult word learning studies remain limited to their static nature rather than a dynamic assessment of how new words are incorporated into a fully developed lexicon.

An additional limitation to previous studies of ND and word learning is that participants were solely presented with the phonological (i.e., auditory) form of a nonword. However, at higher levels of education, adults typically have the benefit of both hearing and seeing an unfamiliar word in print. As such, exposure to a word's spelling has the potential to interact with any influences of ND. To the author's knowledge, no adult word learning study to date has provided orthographic representations of stimuli varying in phonological ND simultaneously with their auditory forms. This may be due in part to the original design of studies to create appropriate tasks for young children. It is possible that adults might use visual information either in conjunction with, or perhaps even to a greater degree than, auditory information in order to maximize word learning. In summary, a lecture-style task must be created where one group of participants is solely exposed to the phonological forms of nonwords varying in ND (hereinafter referred to as ortho-), and another group is presented with both the orthographic representations and phonological forms of nonwords varying in ND (hereinafter referred to as ortho+).

Predictions

Given that an advantage has repeatedly been found for adults in learning dense relative to sparse words (Stamer and Vitevitch 2012; Storkel et al. 2006, Storkel et al. 2014; Freedman 2015), it is predicted that adults in the ortho- condition will perform similarly. However, in the ortho+ condition, it is predicted that no effects of ND will be found. Once visual information is provided, effects of ND may be modulated by the use of other cognitive tools (e.g., visual working memory, mnemonic devices). If this occurs, participants in the ortho+ condition would be expected to learn dense and sparse words to a similar degree. Previous work supports this prediction. Larsen and Baddeley (2003) reported that when words were visually presented to patients with phonological working memory deficits, typically observed phonological similarity effects were no longer present. Similarly, as the level of difficulty increased for participants in a word learning task, learners tended to bypass phonological working memory in favor of other cognitive tools such as visual coding (Larsen and Baddeley 2003; Neath et al. 2003). Finally, based on prior investigations of orthography and adult word learning (Rastle et al. 2011;

Saletta et al. 2016a), it is predicted that, irrespective of ND, participants in the ortho+ condition will learn more nonwords to a greater degree than participants in the ortho– condition. Participants in the ortho+ condition may consciously use orthography as a mnemonic device to support phonological learning regardless of ND. This might occur by integrating the orthographic forms of nonwords into newly-formed lexical representations (Saletta et al. 2016a).

2. Materials and Methods

2.1. Participants

Fifty undergraduate students at Ithaca College participated in the study. Participants were recruited from undergraduate courses and through electronic college announcements. Based on self-report, all participants were native speakers of English without any history of speech, language, or hearing impairment. Prior to the task, each participant signed an informed consent form previously approved by the college's Human Subjects Research Committee.

2.2. Stimuli

Eight consonant-vowel-consonant (CVC) nonwords (displayed in Table 1) were selected from a similar word learning study of this nature (Freedman 2015). In that study, naming accuracy averaged 44% after one exposure, 65% after four exposures, and 67% during retention testing. Therefore, the number of nonwords was not increased in the current task in order to ensure adequate learning; otherwise, floor effects could obscure potential learning differences related to the variables of interest. Using the most traditional metric of operationalizing phonological similarity, ND was determined by the number of words created by deleting, substituting, or adding a single phoneme to a target item (Landauer and Streeter 1973; Luce and Pisoni 1998; Freedman et al. 2016). Consistent with prior investigations, ND values were calculated using the Hoosier Mental Lexicon (Nusbaum et al. 1984). Stimuli were divided at the median value for ND: Words above the median were classified as dense, and words at or below the median value were classified as sparse. This methodology is consistent with related work (e.g., Han et al. 2016; Storkel 2001). Sparse words had a mean ND of seven neighbors (sd = 2.94; range = 3–10), and dense words had a mean ND of 23 neighbors (sd = 7.39; range = 16–32). A paired-samples *t*-test confirmed that dense nonwords had significantly more neighbors than sparse nonwords, $t(3) = 4.41, p < 0.05, d = 2.85$. In order to avoid the influence of other sublexical and lexical factors during word learning, the two ND conditions did not significantly differ in any of the following variables: neighborhood frequency (the word frequencies of a word's neighbors, $t(3) = 0.37, p = 0.74, d = 0.32$), phonotactic probability (positional segment frequency, which is the frequency that a given sound occurs in a given word position, $t(3) = 1.61, p = 0.21, d = 1.31$), biphone frequency, which is the likelihood that two adjacent sounds co-occur in a given word position, $t(3) = 1.36, p = 0.27, d = 0.95$), or orthographic ND (the number of orthographic neighbors following the aforementioned definition of a neighbor, $t(3) = 0.30, p = 0.78, d = 0.29$).

Semantic information was assigned to each nonword by randomly pairing it with a picture of a novel visual object. Pictures of the objects were piloted to five native speakers of English, who were unable to name any of the objects. Objects were designated to one of four semantic categories: animals, food, musical instruments, or tools. Each category contained a dense nonword and a sparse nonword. Therefore, two tools were presented in the lecture (one dense, one sparse), two animals (one dense, one sparse), and so forth. Considering the possibility that some objects might attract participants' attention more than others (e.g., familiarity, shape), pairing of the nonword stimuli was counterbalanced across two different versions of the lecture. For example, a particular animal was associated with a dense nonword in one version, and in the other version it was associated with a sparse nonword.

Orthographic forms for the nonwords (see Table 1) were obtained by creating three possibilities for each nonword using general English spelling conventions. The resulting choices for each stimulus were presented with their phonological forms to six native speakers of English. Participants were asked

to select the spelling choice for each nonword that best matched its auditory form. The orthographic representations selected by at least half of the participants ($M = 4.6$, $sd = 1.05$, range: 3–6) were selected as the final representations for the task.

Table 1. Nonword stimuli by neighborhood density (ND) and semantic group.

Phonological Form	Orthographic Form	ND	Condition	Semantic Group
/baɪn/	<i>byme</i>	16	dense	animal
/jɒt/	<i>yut</i>	3	sparse	animal
/deɪk/	<i>dake</i>	26	dense	food
/kɪb/	<i>kieb</i>	8	sparse	food
/pɒt/	<i>poat</i>	32	dense	musical instrument
/mʊg/	<i>moog</i>	7	sparse	musical instrument
/gɪn/	<i>gien</i>	18	dense	tool
/nɛp/	<i>nep</i>	10	sparse	tool

2.3. Procedure

All participants attended one experimental session in small groups with up to a maximum of five individuals. Each group was randomly assigned to either the orthographic condition (ortho+; $n = 25$) or phonological condition (ortho−; $n = 25$). Participants sat in a semi-circle facing a computer screen and a live presenter at the front of the room. The two-part lecture was presented using Microsoft PowerPoint, consistent with students' typical experiences in a classroom setting (Marzilli et al. 2015). Live presenters followed a standard script in order to ensure consistency between presentations. The first part of the lecture introduced participants to a fictitious culture, (e.g., geographic location, population size). Following the introduction, participants learned about the culture's food, tools, animals, and musical instruments. Only one novel object was presented on the screen at a given time. Nonwords in each semantic pair were presented in sentence-final position following similar syntactic constructions (e.g., "One tool commonly found in the kitchen is a *nep*. It helps people mash ingredients together when preparing dishes.", "Another tool commonly found in the kitchen is a *gien*. It is very sharp and people have to be careful when using it."), and counterbalanced for presentation (e.g., dense-sparse, sparse-dense). Exposure to the nonwords gradually increased during the lecture. In the first part of the lecture, one exposure of each nonword was presented, and three additional exposures were provided during the second part of the lecture using different sentences; syntactic constructions remained identical between dense and sparse stimuli. Each participant was therefore presented with four exposures per nonword, consistent with prior word learning studies of this nature (Freedman 2015; Storkel et al. 2006). In the orthographic condition (ortho+), the spelling of each nonword was presented on the screen as it was pronounced. In the phonological condition, (ortho−), no spellings were provided while the words were pronounced.

Following each part of the lecture, a picture-spelling task was administered. During the task, visual objects from the narrative appeared one at a time on the screen. Participants were prompted to write down the name of each nonword in their packet, and informed that spelling did not matter. Each packet was collected before the task continued in order to prevent participants from altering their answers upon further exposures to the nonwords. Lastly, retention was tested via the same task after a 10-min distractor task (i.e., solving riddles). In conclusion, learning of the nonwords was assessed at three points in time: following one exposure (Part 1), following four exposures (Part 2), and 10 min post-exposure. Feedback on participants' accuracy was not provided at any time.

2.4. Data Analysis

Response accuracy was determined by comparing the featural properties of the responses to the target segments. Using a segmental measure proposed by Edwards, Beckman and Munson

(Edwards et al. 2004), each of the two consonants in a target nonword was analyzed according to a three-point scale: voicing, place of articulation, and manner. Vowels were not scored because of the high variability associated with orthographic representations of English vowels (e.g., /i/ → see, sea, seize, chief). One point was awarded for each correct consonantal feature; therefore, each phoneme could receive a maximum of three points. Given that each CVC nonword in the task had a total of two consonants, participants could earn up to six points per production (2 consonants × 3 points per consonant). Alternative spellings were not penalized (e.g., 'eu' as in eulogy for [j]). Substitution errors containing the first and last consonant of a different target nonword were not scored; these productions accounted for roughly 9% of the data. In summary, two accuracy scores were calculated for each participant: response accuracy of dense words, and response accuracy of sparse words. Inter-rater scoring reliability was calculated on all responses for two-thirds of the participants. Mean point-to-point scoring agreement reached 99% (sd = 0.93, range = 95.8–100%).

2.5. Experimental Design and Analyses

A mixed model analysis of variance (ANOVA) was used to analyze the data. Condition (ortho+ vs. ortho–), ND (dense, sparse), and time (one exposure, four exposures, retention) served as the independent variables, and response accuracy served as the dependent variable. The data were therefore analyzed in 2 (condition) × 2 (ND) × 3 (time) ANOVAs, which were performed on arcsine transformed data to meet the normality assumption. An alpha level of 0.05 was used for all statistical tests. Additionally, a by-items analysis was conducted by calculating the average number of errors made to each nonword across the group.

3. Results

3.1. Statistical Analysis

Statistical results are provided in Tables 2 and 3. Consistent with predictions, participants in the ortho+ condition learned nonwords to a greater degree than participants in the ortho– condition, $F(1,96) = 11.63, p < 0.01, \eta_p^2 = 0.108$. There was no main effect of ND, $F(1,96) = 0.84, p = 0.36, \eta_p^2 = 0.009$, but there was a significant interaction of condition and ND, $F(1,96) = 4.91, p = 0.03, \eta_p^2 = 0.049$. Post-hoc analysis using Fisher's Least Significant Difference (LSD) procedure revealed that participants in the ortho+ condition learned significantly more sparse nonwords than participants in the ortho– condition; dense nonwords were learned to a similar degree. There was also a significant interaction of condition and time, $F(2,192) = 5.57, p < 0.01, \eta_p^2 = 0.055$, as illustrated in Figure 1. Post-hoc analysis using Fisher's LSD procedure indicated that participants in the ortho+ condition learned nonwords to a greater degree than participants in the ortho– condition after one exposure; no significant differences were found after four exposures or during retention testing. There was no significant interaction between time and ND, $F(2,192) = 3.04, p = 0.05, \eta_p^2 = 0.031$, or between condition, ND, and time, $F(2,192) = 0.37, p = 0.69, \eta_p^2 = 0.004$. Lastly, there was a main effect of time, $F(2,192) = 189.49, p < 0.01, d = 2.27, \eta_p^2 = 0.664$. Naming accuracy increased between one and four exposures, as well as between one exposure and retention testing. No significant differences were found between four exposures and retention. Given the possibility that the higher accuracy observed in the ortho+ condition could mask potential effects of ND in the ortho– condition, paired-samples t-tests were conducted for each condition comparing dense and sparse nonwords. For the ortho– condition, a significant effect of ND was found, $t(74) = 2.88, p < 0.01, d = 0.38$. Dense words were learned more accurately than sparse words. This finding is consistent with prior work (Stamer and Vitevitch 2012; Storkel et al. 2006). As predicted, no effect of ND was found for the ortho+ condition, $t(74) = 1.73, p = 0.09, d = 0.18$.

Table 2. ANOVA for condition, ND, and time.

	F-Value	p-Value	η_p^2
Condition	11.63	<0.01 *	0.108
ND	0.84	0.36	0.009
Time	189.49	<0.01 *	0.664
Condition * ND	4.91	0.03 *	0.049
Time * ND	3.04	0.05	0.031
Condition * Time	5.57	<0.01 *	0.055
Condition * ND * Time	0.37	0.69	0.004

Note: * $p < 0.05$.

Table 3. Paired samples *t*-tests for ND by condition.

	t-Value	p-Value	Cohen's <i>d</i>
Ortho-	2.88	<0.01 *	0.38
Ortho+	1.73	0.09	0.18

Note: * $p < 0.05$.

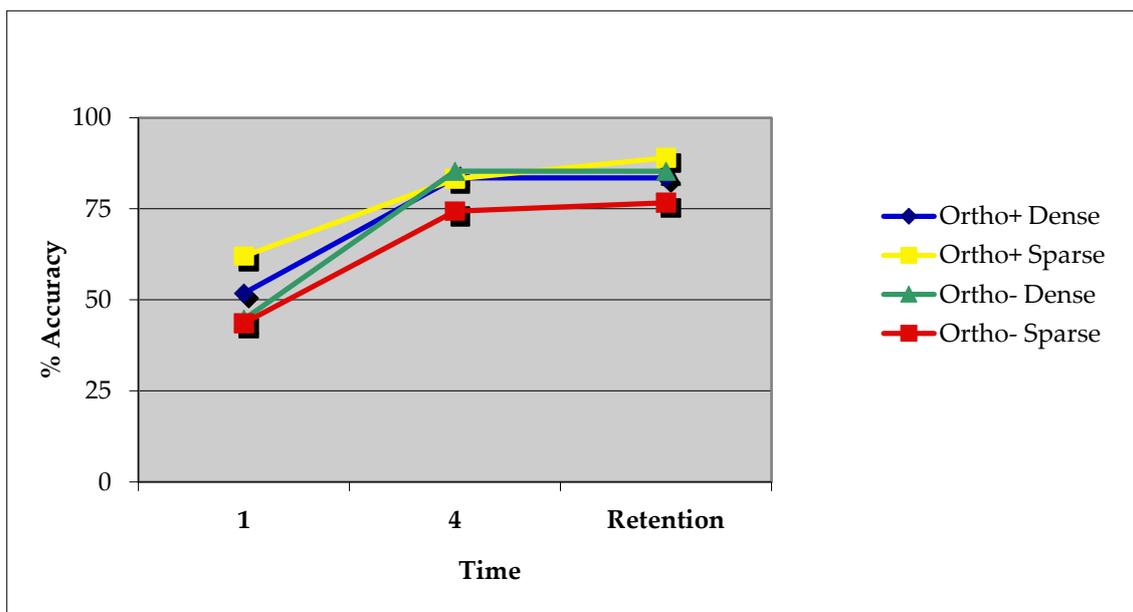


Figure 1. Mean percentage accuracy for word learning by condition, neighborhood density, and time.

3.2. By-Items Analysis

As seen in Table 4, the stimuli learned most accurately during the task were *kieb* ($M = 0.70$ errors, $sd = 0.52$) and *dake* ($M = 0.72$ errors, $sd = 0.70$), a sparse and dense word, respectively. Interestingly, these two stimuli were assigned to the semantic category of food. The stimuli that were learned least accurately during the task were *nep* ($M = 1.17$ errors, $sd = 0.59$) and *gien* ($M = 1.19$ errors, $sd = 0.69$), a sparse and dense word, respectively. These two stimuli were assigned to the semantic category of tools. Lastly, the most improved stimuli during the task were *moog* ($M = 1.59$ fewer errors) and *poat* ($M = 1.59$ fewer errors), a sparse and dense word, respectively. These two stimuli were assigned to the semantic category of musical instruments. In summary, for the group as a whole, it appears that an individual word's ND did not influence its acquisition as much as its semantic category. Nonwords

assigned to food were the easiest to learn, while nonwords assigned to tools were the most difficult to acquire.

Table 4. By-items analysis: Most and least accurately learned stimuli.

	<i>M</i> Errors	<i>sd</i>	Semantic Group
<i>kieb</i>	0.70	0.52	food
<i>dake</i>	0.72	0.70	food
<i>nep</i>	1.17	0.59	tool
<i>gien</i>	1.19	0.69	tool

4. Discussion

The purpose of the present study was to investigate the effects of ND on adult word learning in the presence or absence of orthographic forms. Previous similar studies have reported a greater advantage of learning dense nonwords rather than sparse nonwords. However, many of these studies administered tasks originally designed for use with young, preliterate children (Freedman 2015; Han et al. 2016; Storkel et al. 2006; Dumay and Gaskell 2006; Gaskell and Dumay 2003), which are not ecologically valid for typical adult word learning contexts. This is particularly true in higher education, where adults acquire new lexical items in the context of related information. In addition, while ND is an index of phonological similarity, it was less certain how exposure to the orthographic forms of novel words might impact this variable; previous studies with preliterate children could not have included this information. As such, the current experiment may be one of the first to explore effects of ND on adult word learning using an ecologically valid task, including the presence of orthographic representations.

4.1. Ortho−: Dense > Sparse.

For participants who solely heard the nonwords during the presentation, dense words were learned to a greater degree than sparse words. This finding is consistent with previous studies (Stamer and Vitevitch 2012; Storkel et al. 2006; Storkel et al. 2014; Freedman 2015). Additionally, a post-hoc qualitative analysis revealed that naming errors of other nonwords (i.e., substitutions) were greater for sparse target words rather than dense target words. This may relate to the degree of phonological overlap facilitating the retention of a novel auditory form in working memory (Roodenrys and Hinton 2002). Aside from working memory considerations, as mentioned in the introduction, it is possible that newly constructed lexical representations of sparse words are integrated into the lexicon to a lesser extent than newly constructed lexical representations of dense words. The current study not only replicates existing findings, but also extends them to college students during a typical lecture-style learning experience.

4.2. Ortho+: Dense = Sparse

For participants who both heard and saw the nonwords during the presentation, dense words were learned to a similar degree as sparse words. It appears that when orthographic representations are provided simultaneously with phonological forms, typically observed effects of ND are absent. It is possible that literate adults are such expert word learners that, when provided with multiple cues across different modalities (listening, reading), visual information is prioritized over auditory information. Perhaps adult participants who are regularly engaged in seeing new words as they are acquired (i.e., college students) rely more heavily on visual working memory than verbal working memory. This may be due in part to the ease of processing novel auditory information in comparison to visual information. Previous work discussed in the introduction supports this conclusion (Larsen and Baddeley 2003; Neath et al. 2003).

Another significant finding of the present study is that participants in the ortho+ condition learned significantly more sparse nonwords than participants in the ortho– condition. This was only found during the earliest stages of word learning. It seems that for novel words that do not sound like many known words (i.e., sparse), having both auditory and visual information available is more beneficial to initiate the word learning process than having auditory information alone. In light of the above findings, multiple modalities do not seem to compete with one another, but rather integrate the information in order to aid rapid acquisition of a lexical form. As discussed in the introduction, incorporating orthographic information into newly-formed lexical representations can facilitate word learning (Rastle et al. 2011; Saletta et al. 2016a). If sparse nonwords have shorter activation periods in working memory than dense nonwords (Roodenrys and Hinton 2002), orthographic information may supplement the learning process in a manner that facilitates a new lexical entry more quickly than when such information is unavailable. Without orthographic information, adults can still acquire novel sparse nonwords, of course, but with relatively decreased speed and accuracy compared to dense nonwords. Turning now to ND, the ease with which a new lexical entry is integrated and stabilized in the lexicon may be influenced by its number of similar existing representations. Dense nonwords have a greater number of real-world neighbors than sparse nonwords; these neighbors may assist in strengthening newly formed lexical representations through spreading activation of shared phonological segments. Such activation would be relatively increased for dense nonwords in comparison to sparse nonwords. Lastly, while prior studies have reported more accurate learning of nonwords only after being exposed to their orthographic forms, these tasks have generally involved simple pairings of nonwords and novel visual objects. The present experiment therefore extends these findings to a novel context, a lecture-style presentation.

4.3. Clinical and Educational Implications

In addition to theoretical contributions, clinical implications may also exist. Given that participants in the ortho+ condition learned sparse words to a greater degree than participants in the ortho– condition, novel words for literate clients with vocabulary goals could always be presented with their spelling. By allowing the learner to both see and hear a novel word in the context of related information (in comparison to isolation), learning seems to be enhanced. Previous work supports this notion for different age groups and levels of reading proficiency (Rastle et al. 2011; Saletta et al. 2016, 2016a). Additionally, functional vocabulary items such as food may be ideal candidates given their relatively high learning accuracy in the current study. Future research is warranted to determine how providing both auditory and visual information may be appropriate for atypical language learners. For example, while orthographic information can facilitate word learning in typically developing children (Saletta et al. 2016b), too much information may impede rather than facilitate learning in children with attentional deficits and/or autism spectrum disorder (Egeland et al. 2010).

4.4. Limitations

Since only monosyllabic, CVC stimuli were used in the present study, it is unknown how ND might interact with different syllable structures (e.g., consonant clusters). It is possible that using multisyllabic stimuli might require increased use of verbal and/or visual working memory, which could influence how ND impacts word learning. In addition, as with any between-participants design, there is always the possibility that participants in the ortho+ condition were simply better word learners than those in the ortho– condition. Random assignment was utilized to address this concern, but future studies could control for this possibility by exposing the same participant to two conditions (ortho+, ortho–) during word learning.

4.5. Future Directions

Given that orthographic ND was controlled for in the present study (e.g., the dense nonword *poat* and the sparse nonword *nep* both have orthographic NDs of 11), it would be informative to create

eight nonwords varying in orthographic ND in addition to phonological ND. Low and high values of orthographic ND, which can be calculated with online corpora such as CLEARPOND (Marian et al. 2012), may be designated using a median split or referencing values found in prior studies of this nature. Orthographic ND may impact word learning differently than phonological ND, particularly given adults' highly developed literacy skills. Perhaps phonologically sparse yet orthographically dense nonwords (e.g., *hup*) would be learned to a similar degree as phonologically dense nonwords. It would also be interesting to conduct the same task with different populations in order to explore developmental effects of ND during word learning (e.g., literate school-aged children).

5. Conclusions

In summary, the current study found that adults learned more dense nonwords than sparse nonwords during a lecture when solely the phonological form was provided. When participants were exposed to both the orthographic and phonological forms of novel words, dense and sparse words were learned at a similar rate. Therefore, learning of sparse words significantly improves when orthographic information supplements the phonological information. Additionally, participants who saw and heard the nonwords learned sparse words to a greater degree.

Acknowledgments: Thank you to the participants in the study, and to Taryn Carlson and Cassandra Stolting for their assistance with task administration and data analysis.

Conflicts of Interest: The author declares no conflict of interest.

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