VOCABULARY LEARNING IN MODALITY-SPECIFIC CONTEXT: BUILDING COMPLETE REPRESENTATIONS

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This study seeks to determine the extent to which phonology and orthography are generated when a word is learned in a single modality (visual or auditory) and how this affects the ability to later recognize that word in the opposite modality. Participants overall required fewer trials to learn words presented visually than auditorily, and performance in a recognition and recall task indicated that the word form representations were better specified with visual training. However, slower vocabulary learners showed a deficit in their ability to accurately recognize words learned visually and later heard. Results indicate that decoding takes place more readily than encoding (used to mean the opposite of decoding) and that slow learners have difficulty forming well-specified phonological representations when given words orthographically.

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1. Introduction

Vocabulary learning occurs throughout life in a variety of forms. Infants must begin the process by learning associations between sounds and meanings. Young children must then learn to map written word forms onto an already established phonological system in order to read, and must learn to spell in order to write. Children and adults also continue supplementing their native language vocabulary and may also choose to learn the vocabulary of another language. While many word learning tasks involve mapping new word forms onto existing word representations (e.g. reading, much of second language vocabulary learning in the classroom), adults often hear or read entirely new words, and must establish representations of those words in the absence of existing lexical information. In these cases where a new English word is encountered in a single modality (visual or auditory), grapheme/phoneme correspondences should enable a person to form a representation of the word both phonologically and orthographically, despite encountering the word in only one form. This ability would be valuable in establishing unified word representations, such that if a learner hears a new word and later reads it, he will be able to recognize the word as being the same and augment the word representation that was already established when the word was heard, although in theory this could also be done primarily through the semantic representation of the word.

While we know that there are connections between orthographic and phonological word representations that allow readers to read and spell words they know, the question remains as to whether the connections primarily link existing word forms, or whether they can actually help establish new word form representations by allowing a person to use a phonologically

encountered word to generate an orthographic representation and to use a visually encountered word to construct a phonological representation. Assuming that a word encountered in a single modality will allow word representations to be formed in the opposite modality to some degree, we can then ask whether this occurs symmetrically for visually and auditorily encountered words, or whether encountering a word in one modality enables a learner to form a more complete word form representation than encountering it in the other modality. Observing a symmetry or a modality dependent asymmetry in the ability to fill in missing word form information will give us more information about the nature of connections between orthographic and phonological representations of word form.

In order to make predictions about the processes that will take place when a new word is encountered in a given modality, we can look to word recognition literature for evidence that phonology and orthography interact in tasks that need only involve information from one modality. To the extent that interactions are pre-lexical, assembled, or automatic, we can predict that interactive processes between modalities will also occur with new words at the sub-lexical level, possibly resulting in the formation of a word representation in a non-given modality.

It is well accepted that phonology plays an important role in visual word recognition. Though there is less current literature about the role of orthography in spoken word recognition, there does appear to be evidence that orthographic information is automatically activated during, and contributes to, spoken word recognition (e.g. Slowiaczek, Soltano, Wieting, & Bishop, 2003) However, this research has been conducted using common known words (or non-words that sound like known words) that are already represented phonologically, orthographically, and semantically. While there have been studies done to examine word learning as opposed to known words, these experiments mostly concern children as they are becoming aware of spelling

to sound correspondences (e.g. Sprenger-Charolles, Siegel, Bechennec, and Serniclaes, 2003). In this case, children usually learn to pronounce written words or spell spoken words that are already represented phonologically and semantically, but that the child does not know how to read.

The critical role of phonology in reading has been demonstrated in a variety of ways and throughout a wide range of the literature regarding reading. The first demonstrations of early, pre-lexical phonological activation during reading came from backwards masking experiments in which phonologically similar masks were less disruptive to target identification than control masks (Naish, 1980; Perfetti, Bell, & Delaney, 1988; Perfetti & Bell, 1991). Since the phonological benefit occurred with a time course that suggests pre-lexical phonological activation, the studies would support the idea that even new words or non-words that don't exist in the lexicon, activate an assembled phonology.

That finding has been further supported by demonstrating homophone and psuedohomophone confusion in categorization tasks (Van Orden et al., 1988), and lexical decision tasks and naming experiments (e.g. Lukatela & Turvy, 1994 a&b; Unsworth and Pexman, 2003). In priming studies, effects of the uniqueness of pronunciation (Lukatela, Savic, Urosevic, and Turvey, 1997) as well as consistency effects (Lukatela, Frost, and Turvey , 1999) verify the activation of phonology in reading. The effects of pseudohomophones and nonwords further support that assembled phonology, in addition to addressed phonology, can play a role in reading, and this idea is important in considering what happens when we encounter new words, for which there is no addressed phonology.

Not only have phonological processes proved important for lexical access, but also for developing orthographic representations, implying that even establishing a word in one modality,

orthographically, is not independent of phonological knowledge. Dixon, Stuart, and Masterson (2002) found that children who scored better on phoneme segmentation tasks were able to learn to read new words with fewer trials while still performing better on post-tests. The authors concluded that children with good phonemic awareness were able to form orthographic representations with support from the phonological system. In contrast, children lacking phonemic awareness were forced to try to make logographic mappings to meaning by fixating arbitrarily on visual aspects of the word, and were therefore less successful. This implies that when encountering a new word visually, having the ability to decode will make visual learning easier, and that this will be dependent on individual differences. The sum of the literature about the role of phonology in orthographic tasks shows that phonology is quickly and automatically assembled when a word is seen, and that phonological awareness contributes to learning orthographic representations.

Orthography has also been shown to have some influence on spoken word recognition, indicating that the connection between phonology and orthography is utilized in both directions, and that if orthographic information is accessed during phonological tasks, it may also be formed during phonological learning. Seidenberg and Tanenhaus (1979) found that rhyme judgments of auditorily presented words were facilitated when the rime units were spelled the same (pie-tie vs. pie-rye), indicating that orthographic information was being used in this judgment, despite being non-advantageous to the task. Slowiaczek et al. (2003) also support the idea that orthography is automatically activated in auditory tasks. Since Seidenberg and Tanenhaus used stimuli which always shared phonology (rhymed) but varied to the extent that orthography was shared, they did not examine whether orthography, even when inconsistent with phonology, has an effect on a phonological task. Slowiaczek et al., on the other hand, used stimuli which shared only

orthography (ratio-ratify), only phonology (nuisance-noodle), both (funnel-funny), or neither (sermon-noodle). Accounting for facilitation in a series of shadowing and auditory lexical decision tasks, they concluded that orthography and phonology both play a role in spoken word processing, and that it was the degree of overlap of both of these components that could provide facilitation. In other words, words that shared more combined phonemes and graphemes caused the most facilitation. In addition, this was only observed in the experiment in which there was a small percentage of related trials, reducing strategic processing. Because of this, they also conclude that orthography and phonology are activated automatically in normal word processing, rather than strategically.

More evidence in support of the idea that orthography plays a role in phonological tasks comes from Castles, Holmes, Neath, and Kinoshita (2003) who argue that phonological awareness tasks have an orthographic component which contributes to the difficulty of phoneme deletion. Specifically, even though phoneme deletion tasks are presented phonologically, participants find it easier to delete phonemes from words which have a letter which represents the phoneme (e.g. taking the /r/ from struggle) than those which do not (e.g. taking the /w/ from squabble). Even when the trial types were blocked, making it advantageous to ignore orthographic information, the effect remained. This is another indication of the automaticity of orthographic activation in phonological tasks. While the literature suggests that orthographic information is automatically activated in phonological tasks, there is not strong evidence that orthography plays a role when it is inconsistent with phonology. Instead, phonological information alone, as well as interactions between phonological and orthographic information, seem to affect lexical processing. This could be specific to English as a result of having more consistent spelling-to-sound correspondences than sound-to-spelling correspondences making

phonological information gleaned from spellings more accurate than orthographic information encoded from pronunciations. (For the sake of brevity, "encode" here and throughout the paper is used to mean the opposite of "decode" -- the formation of an orthography from phonological information.) The stronger evidence for phonological effects on reading could also be more cross-linguistically universal, based on the fact that we first learn language verbally, and later learn to read by mapping written forms to existing phonological representations, making decoding a more integral process to language than encoding.

More recently, a word learning study was conducted by Johnston, McKague, and Pratt (2004) showing that an automatically accessible orthographic representation of words is formed even when the words have only previously been heard. This was evidenced when, after phonological training on rare words, the previously unseen orthographic forms of those words primed their identification in a lexical decision task. This was true even when the inclusion of pseudohomophone foils inhibited the use of phonological information in the primes. However, the authors also determined that the orthographic representations were under-specified, since any orthographically similar word caused equal priming, whereas identity primes facilitated the lexical decision of known words above other orthographically similar primes. They concluded that since orthographic information was automatically or strategically generated during the learning process, orthography must be more important to word representations than theories having a "core" phonological representation such as Frost argues for (1998) would assume. They argue that the role of orthography could be either in the form of more equal interconnected orthographic and phonological representations, or in the form of a modality neutral representation. Their study, however, did not directly compare orthographic and phonological representations, or the formation of them, to determine if the two are equal in importance or

degree to which they are formed during learning in the opposite modality. The current study addresses this by comparing learning in both auditory and visual modalities, and testing recognition in both modalities.

The degree to which orthography and phonology play a role in lexical processing may be strongly influenced by the reader's skill level. Hogaboam and Perfetti (1978) showed that compared to less-skilled readers, skilled readers are faster decoders. In addition, given only a small number of exposures to a new word, skilled readers benefit in later naming the word, whereas less-skilled readers require many exposures to show improvement. Unsworth and Pexman (2003) examined skill level closely by looking at the effects of homophones, homographs, and regularity on both orthographic and phonological tasks for readers of different skill levels. The most consistent finding was that less-skilled readers were susceptible to regularity effects in both orthographic and phonological tasks. They concluded that skilled readers have more efficient orthographic-phonological mappings. While both skill levels activate phonology in both kinds of tasks (as seen in the case of homophones), only the less-skilled group seems to have spurious phonological activation as evidenced by regularity effects.

Separate lines of research show the involvement of phonology in reading and written word learning and the involvement of orthography in listening and phonological word learning. In the current study, we sought to extend research in the domain of word recognition to the domain of vocabulary learning and determine whether lexical information in a non-given modality can not only be accessed, but can be created by the vocabulary learner. If so, we can then make a direct comparison to determine whether the phonological information derived from newly encountered written words is equal in quality to orthographic information derived from

newly encountered spoken words. In addition, we examined the role of individual differences in the ability to form complete representations of words learned in a single modality.

To do this, we trained participants on the meanings of rare words presented either visually or aurally. After learning the words to criterion, they were presented with the words in either the same modality as learning or in the opposite modality along with untrained rare word foils. They were asked if the words were learned, and if so, in what modality the words were presented during training. If one modality is easier to learn than another, we should see evidence from the number of trials required to reach criterion. If representations of words are formed in the modality that was not given, we should see this in better-than-chance recognition accuracy for words presented in the untrained modality. However, we would still expect to see evidence of encoding specificity (Tulving, 1983) so that participants would more accurately recognize words given in the same modality at the time of testing. To the extent that formed representations are asymmetrical depending on the trained modality, we should see differences in recognition accuracy between the two training conditions when words are presented in the opposite modality during testing. By looking at various measures of reading skill, we can also examine whether skill influences a person's ability to form complete representations of words when they are given limited information about the word. Further, we can determine whether skill specifically affects one modality more than another.

2. Methods

Approximately 500 undergraduate students from the University of Pittsburgh were recruited to complete a battery of tests designed to assess comprehension ability and vocabulary knowledge for course credit. Of these students, 35 were recruited to participate in this study for compensation. Readers of varying comprehension ability based on their scores for the Nelson-Denny comprehension test, were recruited to participate. Each subject was paid $21 dollars for their participation in the three hour study. In the event that it did not take the full 3 hours because the participant was able to complete the training portion in less than the allotted 2.5 hours, the participant was still compensated $21. This acted as incentive to work quickly to achieve the goal. The study was composed of two portions: a training portion, in which participants learned new rare vocabulary words, and a testing portion, in which participants were probed on the words.

2.1. Materials

The Nelson-Denny reading comprehension and vocabulary tests were administered to each subject participating in the experiment. Accuracy scores were calculated based on the percent correct out of those tried, and speed scores were simply the number of questions attempted in the given time limit. Fifteen minutes were allowed for the comprehension test, and seven and a half minutes were allowed for the vocabulary test. 105 rare words were used for training and 35 additional words were used as rare word foils for testing. The mean length of trained words was 7.0 characters, and the mean number of syllables was 2.5. Trained words ranged from 4 to 9 characters and were all either 2 or 3 syllables. The rare word foils had a mean word length of 7.4 characters and 2.6 syllables, although they were more variable, ranging from

4 to 11 characters and 1 to 5 syllables. All stimuli are listed in the appendix. Stimuli were displayed and responses recorded using E-Prime software from Psychological Software Tools.

2.2. Training Portion

The training portion lasted 2.5 hours or until the participant was trained to criterion (100% correct), whichever came first. If the subject did not reach criterion within 2.5 hours, they went on to participate in the assessment and testing session. If the participant reached criterion in less than 2.5 hours, they were still paid for the full 2.5 hours and they continued on to the assessment and testing portions. This was incentive to learn the words quickly and thoroughly. The subjects were trained on thirty-five rare words in each of three training conditions (amounting to 105 words total, given in the appendix). The training was self-paced so that the participant could spend as much time on any word as needed. The training conditions were as follows:

orthography/meaning: In this condition subjects were required to learn the meaning of each word given its written form. They saw the word presented along with its definition and an example sentence during training.

orthography/phonology: In this condition subjects were required to learn the pronunciation of each word given its written form. They saw and heard the word during training. They were able to hear the pronunciation of the word as many times as needed by pressing a key.

phonology/meaning: In this condition subjects were required to learn the meaning of each word given its pronunciation. They heard the word presented along with its definition and an example sentence during training. In the example sentence, the word of interest was replaced with a blank space to ensure that they were not exposed to the orthographic form of the word. Again, they were able to hear the pronunciation of the word as many times as needed by pressing a key.

2.2.1. Initial Familiarity Check

For each subject, the 105 words were randomly divided into three sets of 35 words, one set for each training condition. The order of the training conditions was counterbalanced across subjects and remained constant throughout the experiment. Words within training conditions were randomized to eliminate order effects. Since the stimuli are real, but very rare words, it is possible that some of the participants already knew, or are familiar with, some of the words. In order to assess this, subjects proceeded through each block once, rating whether each word was familiar by pressing 1 or 2. As long as a response was given within 4 seconds, the definition (in the orthography/meaning and phonology/meaning conditions) or pronunciation (in the orthography/phonology condition) was given, and the participants were able to study each word as long as they want. Participants were reminded of the instructions at the beginning of each training condition block. The experimenter left the room during this portion so that participants would not feel rushed. They proceeded through the entire list once at their own pace.

2.2.2. Reaching Criterion

After the familiarity check was completed, the experimenter returned. Participants then proceeded through the list of words, which remained blocked by training condition, with the experimenter. Subjects either saw or heard the word, and they were required to give the appropriate definition or pronunciation, depending on the condition, aloud. The experimenter judged whether the definition or pronunciation was correct and keyed in a response. This prompted a feedback screen telling the participant whether they were correct or incorrect, and gave the correct answer. Regardless of whether the participant was correct or not, they had a chance to study the correct answer again for as long as they needed before proceeding to the next word.

The participant and experimenter proceeded through the list of words in this manner as many times as needed for the subjects to learn 100% of the words. When a participant gave the correct definition or pronunciation for a given word twice in a row, the word was considered learned and was removed from the list. That word did not appear again in the remainder of the training portion. Criterion was reached when participants correctly answered 100% of the words twice in a row so that no words remained in the list.

2.3. Testing Portion

In the testing portion, subjects were presented with a series of words. 1/3 of the words were words from the orthography/meaning condition, 1/3 of the words were the words from the phonology/meaning condition, and 1/3 of the words were rare, unstudied words. Half of the words from each condition were presented in spoken form, and half were presented visually. This creates four conditions: O-O (words learned orthographically and tested orthographically), P-P (words learned phonologically and tested phonologically), O-P (words learned orthographically and tested phonologically), and P-O (words learned phonologically and tested orthographically. Table 1 shows the breakdown of the stimulus training and presentation. The words were presented randomly during the testing portion, intermixing those presented auditorily and those presented visually.

The task was to recall whether the words were seen, heard, or not given (in the case of the untrained words) during the training portion. Participants were asked to rate their certainty using the scale shown in Figure 1. It was emphasized that they should judge based on the modality in which they were given the word *in the training portion of the experiment* regardless of how the word is given in the testing portion, and regardless of whether they have had previous experience with the word. After each word was presented once, the list was presented again in random

order with each word given in the other modality. Only the data from the first presentation of each word was considered since it is possible that the first presentation of the word in testing added to the representations formed during training and affected responses for the second presentation. The testing portion was untimed, but was generally completed quite rapidly.

3. Results

Initially, the responses of the subjects were scored in terms of whether they accurately characterized the items as old or new, regardless of the modality in which they reported having learned the word. A two-way repeated measures ANOVA was performed with two levels of training: orthography-meaning (OM) and phonology-meaning (PM), and two levels of testing: same modality and different modality. There was a significant effect of testing such that words given in a modality different than training were less accurately recognized, with a mean difference of 16.0%, $F(1,34) = 73.64$, $MSE = .012$, $p < 01$. There was also a significant effect of training $F(1,34) = 4.99$, $MSE = .006$, $p < .05$ driven by the significant interaction between training and testing $F(1.34) = 7.63$, $MSE = .006$, $p < .01$; while subjects were impaired at word recognition when the words were presented in a different modality, this impairment was were worse when they had learned the words orthographically and then heard them at the time of testing (O-P) than when they were trained phonologically and then saw the words at test time (P-O) as shown in Figure 2.

In order to look more closely at this interaction, given that the same-modality conditions did not differ significantly from each other, we calculated difference scores for each of the thirty-five subjects in which the recognition accuracy for the O-P was subtracted from the P-O accuracy. Thus, any subject with a positive "differential recognition impairment" showed the same pattern as the overall results – they suffered more when visually trained words were presented aurally than when phonologically trained words were tested visually. Those with a score of zero did not show the interaction, and were equally able to recognize words in both different-modality conditions. A negative score indicates that a participant showed a pattern opposite from the overall results – they were less likely to recognize a word they learned

phonologically and then saw later. Each of the thirty-five participants is plotted as a point in Figure 3.

An analysis of the thirty-five individual subjects showed that only a subset of participants followed the pattern seen in the overall data: an inferior recognition performance for words learned visually and tested auditorily. Thirteen of the thirty-five subjects showed an effect in this direction with a magnitude of at least a 10% difference in accuracy. The subjects showing this effect varied in the extent to which they were worse at the O-P condition than the P-O condition, ranging from 10% to 44% less accurate at recognizing the words as old. However, many subjects showed no difference in the two different-modality conditions. Nineteen subjects ranged between a -5.0% and 5.0% accuracy difference (eight subjects showed exactly zero difference), and only three subjects showed accuracy differences of 10% or more in the direction opposite from the main finding; they performed worse when words were learned phonologically and later seen.

In order to determine whether reading or vocabulary scores were interacting with the training modality x testing modality interaction, a repeated measures ANOVA was done with Nelson-Denny test scores, divided into three skill groups, systematically added as between subjects variables. Comprehension test speed, comprehension test accuracy, vocabulary test speed, vocabulary test accuracy, and initial familiarity ratings did not interact with the training modality x testing modality interaction, suggesting that it was neither the skill of the reader nor their knowledge of vocabulary that predicted whether they would show this effect. In addition, there were no main effects of any of these variables.

To assess vocabulary learning skill, as opposed to reading skill or vocabulary knowledge, the participants were divided into three groups based on their speed at learning the vocabulary

words. This was calculated by averaging the number of trials needed to reach criterion in the two training conditions of interest: orthography-meaning (OM) and phonology-meaning (PM) and dividing the subjects into equal groups of fast, average, and slow learners. Table 2 shows the mean trials to criterion for each group.

Because the speed at learning words in the orthography-meaning condition was significantly correlated to the speed at learning words in the phonology-meaning condition ($r(33) = .83$, $p<.01$), subjects were not divided by their performance in each condition separately. However, it should be noted that words in the orthography-meaning condition were learned significantly faster than words in the phonology-meaning condition for all groups, by 0.60 exposures, in a paired t-test, $t(34) = -4.24$, $p<.001$.

The learning speed distinction proves to be useful, because group, used as a between-subjects measure, significantly interacts with the training modality x testing modality interaction in a repeated-measures ANOVA, $F(2, 32)=8.54$, $p<.01$. Only group three, those who are relatively slow learners in both the orthography-meaning and phonology-meaning training conditions, show the training modality x testing modality interaction; they are worse specifically at recognizing words they learned visually and later heard (the O-P condition). The faster two groups of learners show only an overall modality difference, with better accuracy for recognizing words in the same modality in which they were learned (see Figure 4).

Since the words were randomly assigned to the different conditions, it is possible that this group happened to get randomly assigned more difficult to pronounce items in the O-P condition making the words difficult to recognize when later heard. The orthography-phonology training condition, in which participants simply learned to pronounce the set of words, was used as a proxy for a measure of pronunciation difficulty. Subjects should require more trials to reach

criterion in this condition for words that are particularly difficult to pronounce. Using this logic, each item's difficulty was determined by averaging z-scores across subjects for the number of trials to criterion in the pronunciation condition. When this average difficulty was entered into the repeated measures ANOVA as a covariate to factor out effects of difficulty, difficulty did not interact with any of the results, and the significant effect remained for the group x training modality x testing modality three-way interaction of interest, $F(2, 31)= 8.478$, $p<.01$.

None of the groups significantly differ from each other in either of the same-modality testing conditions (O-O and P-P) or in the P-O condition. In a one-way ANOVA, only the O-P condition differs between groups, $F(2, 32)=9.52$, $p<.01$, and the Bonferroni post-hoc test shows that group three (slow learners) differs significantly from both groups one and two in this condition ($p<.001$, $p<.05$, respectively) while groups one and two do not differ significantly from each other.

The results are very similar for modality accuracy – the percentage of correctly recognized items whose training modality was also correctly identified. A one-way ANOVA reveals that again, only the O-P condition differs between groups, $F(2, 32)=5.58$, $p<.01$, (see Figure 5). The Bonferroni post-hoc test showed that group 3 (the slow learners) performed reliably worse than group 1 (the fast learners), $p<.01$, but that group 2 did not differ from group 1 or group 3. There is also, however, a large difference between the pattern of data for modality accuracy and recognition accuracy. Recall that recognition accuracy showed a main effect of training condition, but that this was driven by the slow learners performing poorly on the O-P condition, lowering the overall orthography training accuracy. In fast and medium vocabulary learners, there was little or no difference between training modalities. While a repeated-measures ANOVA for modality accuracy also shows a significant effect of training condition,

$F(1, 34)=11.63$, $MSE=.011$, $p<.01$, it is in the opposite direction of the effect found in recognition accuracy. Subjects were less accurate at identifying the source modality for words trained phonologically, despite worse performance by slow learners in the O-P condition. Figure 5 makes clear the fact that learners of all skill levels show worse performance for modality recognition when the word was learned phonologically.

The phonologically trained words seem to be less well-specified, as evidenced by the fact that subjects are less able to recall the modality in which the word was learned. It seems they are more likely to be basing their recognition for phonologically trained words on a general feeling of familiarity with the word, but not a specific representation of the word, even in the same-modality condition.

3.1. New Words

New words were equally likely to be mistaken as old regardless of the modality in which they were presented, and regardless of the group the participant was in. However, there was a significant difference in the responses given for recalled training modality, such that new words presented visually were rated as being learned auditorily (average rating of 5.3 on the 7 point scale), and words presented auditorily were rated as being learned visually (average rating of 3.1). For the 23 subjects who missed at least one visually presented and one auditorily presented new item, a paired samples t-test showed the difference between mean ratings was significant ($t(22)=3.514$, $p<.01$). Thus, it is evident that when a word feels familiar, but has no real representation, participants will guess that they learned the word in the opposite modality. When a new word was heard and mistakenly identified as old, participants were about twice as likely to say that it was previously seen in training as they were to say it was heard, whereas when a new

word was *seen* and mistakenly identified as old, participants were nearly nine times as likely to guess that the word was heard in training.

3.2. Discussion of Bias

Before considering the meaning of the data, we must first consider how the new word bias affects our interpretation of the data for learned words. Since participants are equally likely to falsely recognize words regardless of the presentation modality, and regardless of vocabulary learning speed, this does not affect the recognition data. However, for modality accuracy data, we could take into account that there may be an overall bias to report that the word was heard in training, as we see with new words. In this case, the two phonology training conditions (P-P and P-O) should have the highest modality accuracy, which is not the case. In fact, the orthography training conditions are overall significantly more accurate than the phonology training conditions. It seems more reasonable to assume that the bias we see for incorrectly recognized new words occurs when a word seems weakly familiar, and a guess must be made as to what modality the word is learned in. For the most part, people will assume they must have learned the word in the modality opposite the one they are being given, since the familiarity feels weak. If people generally feel that they have more well-specified orthographic representations in this task, they will be particularly likely to assume that they must have heard a weakly recognized visually presented word. On the other hand, if a heard word seems familiar and the assumption is that their phonological representations are somewhat less well- specified, participants may be more likely to entertain the possibility that they actually heard that word before. This would explain the discrepancy between the amounts of bias in the two presentation modalities.

If the same bias holds true not only for new words, but also for the more weakly recognized learned words, then it should apply to the two different-modality testing conditions,

since words in these conditions are less likely to be recognized at all. The bias to assume that the word was learned in the opposite modality inflates the modality accuracy data for those two conditions (since the word was, in fact, learned in the opposite modality), but more so for the P-O condition, since the bias is stronger for visually presented words. This means that for the participants who have lower performance in the O-P condition, we are actually seeing a conservative estimate of their uncertainty, since the bias is in their favor to improve accuracy. This is even more the case in the P-O condition. It is possible that participants are actually uncertain on many of the items, but with such a strong bias to guess that the word was learned in the opposite modality, it is impossible to tell whether there might be group differences in how often they are guessing in the P-O condition, or whether perhaps all groups would be less accurate but still equal if there were no bias. For example, it could be the case that two groups are actually guessing 100% of the time, thus achieving 90% accuracy, and that two of the groups are correct 50% of the time and guessing 50% of the time, leading to a similar 95% accuracy, even though significantly more words are accurately recalled.

Despite the presentation-modality dependent unequal bias for incorrectly recognized new words, we can safely assume that the modality accuracy for the two same conditions and the O-P condition are probably a fair reflection of the groups' cognitive performance, as described above. The P-O condition, however, may be inflating participants' accuracy in one or more of the groups. Despite this, the recognition accuracy for all conditions should not be affected by this bias.

4. Discussion

Three separate tasks are considered in the results of this experiment: learning a vocabulary word quickly, recognizing that a given word has been previously learned, and recalling the modality in which it was learned. The recognition task requires only a general sense of familiarity with an item, whereas success in the modality recall task requires a more well-specified representation of the vocabulary word. Similar to, and supported by an argument made by Johnston and his colleagues (2004), the fact that this task requires recognition in a form other than that in which it was learned implies that it is not merely an episodic memory task which calls upon information in a separate, nonlinguistic, memory store. Instead, it is more likely that the task taps into the lexicon and utilizes lexical processes. If we begin with these assumptions, we can interpret low accuracy in the recognition task to mean lack of familiarity, and low accuracy in the modality task to mean that there is not a well-specified representation of the words that are accurately recognized, only a general sense of familiarity.

In order to first understand how a skilled participant performs in the given tasks, we can examine the patterns of group one. The skilled participants (and in fact all participants) require fewer trials to learn the orthography-meaning words than the phonology-meaning words. This data is similar to that published by Baddeley, Papagno, and Vallar (1988). They found that subjects were faster to learn word-nonword pairs visually than auditorily, consistent with the vocabulary learning data presented here, and point out that "it is possible that memory for nonwords in our study might be enhanced by visual presentation because this allows both a phonological and a visual encoding of the unfamiliar material" (p.591). Atkins and Baddeley shed some light on this issue (1998) with their finding that phonological memory span, but not visuo-spatial span, is correlated with the speed of learning vocabulary words in a new language.

Since this correlation is true even for words trained orthographically, they conclude that new visually presented words are phonologically recoded. The fact that a specified orthography is given probably both strengthens the generated phonological representation and adds a well-specified orthographic representation. On the other hand, if it is difficult to generate a well-specified phonological form in the absence of orthography, and more difficult to generate a missing orthography than a missing phonology, we would expect words learned phonologically to get little support from their corresponding, weakly generated, orthographic forms.

It could instead be the case that the connection from orthography to meaning is stronger than the connection from phonology to meaning, enabling faster vocabulary learning. If that is the case, then once words are learned to criterion, there should be relatively small differences between any data looking only at form information – instead we see that even though orthographic words are learned more quickly and thus have fewer exposures, they are more accurately recalled than phonologically studied words in the modality accuracy task, which requires no meaning retrieval. This indicates some difference in the quality of the form representations. In addition, the stronger bias to guess that unlearned but familiar words were learned phonologically supports the idea that the phonological representations learned in this task may be under-specified compared to the orthographic forms learned. Participants are better at "knowing" when a visually presented word does not match an actual learned visual form than "knowing" when an auditorily presented word does not match an actual auditory form they learned. Gallo, McDermott, Percer, and Roediger (2001) reached a similar conclusion when they found that the probability of falsely remembering a probe item which was semantically related to, but absent from, a given list increased when the list was presented auditorily and tested visually. They discuss several ideas about the possible cause for this pattern of results, including

that phonological memory may be more difficult to distinguish from thought than visual memory, that visual recollections may be more distinct than phonological ones, and the absence of visually encoded items in memory is more salient than the absence of phonologically encoded items when comparing test items to memory. In short, we can conclude that the learning pattern in the skilled group, when combined with the bias seen with new words, is consistent with a group of good decoders who can form well-specified representations when given orthography, and somewhat more underspecified representations when given only phonology.

Given this assumption, why then does group three, the slow learners, have trouble recognizing words in the orthographically learned, modality-different testing condition, but not the phonologically learned, modality-different testing condition, even though they too are faster at learning words orthographically? If this group is also better at decoding than encoding, but is less able to maintain strong phonological representations, we would still expect an advantage for learning orthographically presented words since, once decoded, both orthographic and phonological information is available. If learning the words to criterion means that the words must be recognized in their given form in order to correctly define them, it is not surprising that the slow learners perform as well as fast learners in the same-modality conditions. Consider now the different-modality testing conditions. In the phonology-meaning training condition, participants have been given the correct phonology of a word and have been required to learn it to criterion. If that word is then presented visually, and decoding takes place, the already established phonological representation may be strong enough to support accurate decoding at test time and resonate a general feeling of familiarity for the visually presented test item. Some combination of the word being recalled in its trained form and the guessing bias would enable relatively high accuracy when determining in which modality a word was learned. On the other

hand, when a word is trained to criterion in the orthography-meaning training condition, the generated phonology may not be as strongly represented as it is for fast learners, and certainly will not be as strong as it is in the phonology-meaning condition when the phonology is explicitly given and learning must occur to criterion. If participants are able to use some combination of orthographic and phonological representations to reach criterion in the orthography-meaning condition, they can reach criterion without forming a particularly strong phonological representation. Then, if a word is heard at test time, a match will be less likely to occur between the given word and this weakly generated phonology. Participants may perform more accurately if they were able to encode the spoken test item and match the orthographic form to the stronger learned orthographic form. However, assuming an imbalance between the ability to decode and encode in which decoding is a superior process (supported by Borowsky, Owen, & Fonos, 1999), explains the experimental results for both fast and slow learners, accounting for the overall faster orthographic learning and the poor performance for slow learners in recognizing aurally presented words they have previously seen. The idea that the factor causing group three difficulty in learning the words and in later recalling words is a phonological memory factor is supported not only by Atkins and Baddeley (1998) but also in other studies (e.g. Gathercole, Willis, Emslie, & Baddeley, 1991; Service & Kohonen, 1995) showing a link between phonological memory and vocabulary acquisition.

From the results of this study, we can draw several conclusions about the way readers interact with new words encountered in different modalities, and we might use this information to inform research on vocabulary learning, possibly in both native language and foreign language situations. First, readers at all levels are more successful at decoding unfamiliar written words than at forming orthographic representations from unfamiliar spoken words. This conclusion

does not contrast with the finding of Johnston et al. (2004) that underspecified orthographic representations are formed from when new words are heard. While some amount of orthographic generation probably occurs when a word is heard, our study suggests that there is an imbalance between the quality of a generated orthographic representation and a generated phonological representation, the latter being of higher quality.

This bias to decode means that when new words are presented in written form, a reader is able to form more complete, higher quality representations than when a new word is presented auditorily, and the word can be learned more quickly. Phonology can be readily generated from the written form, and the orthographic form will both provide its own information and support the generated phonological form. This is the case for both fast and slow learners. However, learners who are not as adept at storing given or generated word forms, possibly because of a weak phonological memory span, will significantly benefit from being given an explicit phonology. While they will also be faster to learn words presented visually, and possibly have more complete representations of those words, they will, as a result of the decoding/encoding inequality, still have difficulty recognizing those words when spoken as they try to make a direct match from the spoken word to a previously self-generated phonology. However, if required to learn the correct phonology for a new word, less skilled learners will be better equipped to recognize new spoken words when later encountered in reading, because decoding can be supported by the existing representation.

5. Tables

Table 1: Stimuli Presentation

Training	Orthography/Meaning (see)		Phonology/Meaning (hear)		Untrained	
Testing	See (O-O)	Hear (O-P)	See (P-O)	Hear (P-P)	See	Hear

Table 2: Mean Trials to Criterion for Vocabulary Training

Group	**Speed**	**Trials to Criterion (orthography-meaning)**	**Trials to Criterion (phonology-meaning)**	**Mean trials to criterion**
Group 1 (n=11)	Fast	2.64	2.93	2.79
Group 2 (n=12)	Medium	3.06	3.77	3.41
Group 3 (n=12)	Slow	4.51	5.22	4.88

6. Figures

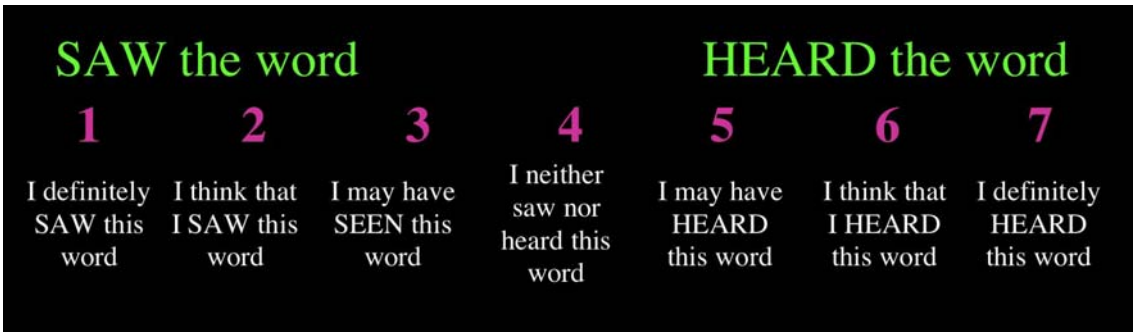

Figure 1: Scale used by participants during the testing portion in which they determine whether the word was previously learned, and if so, in what modality.

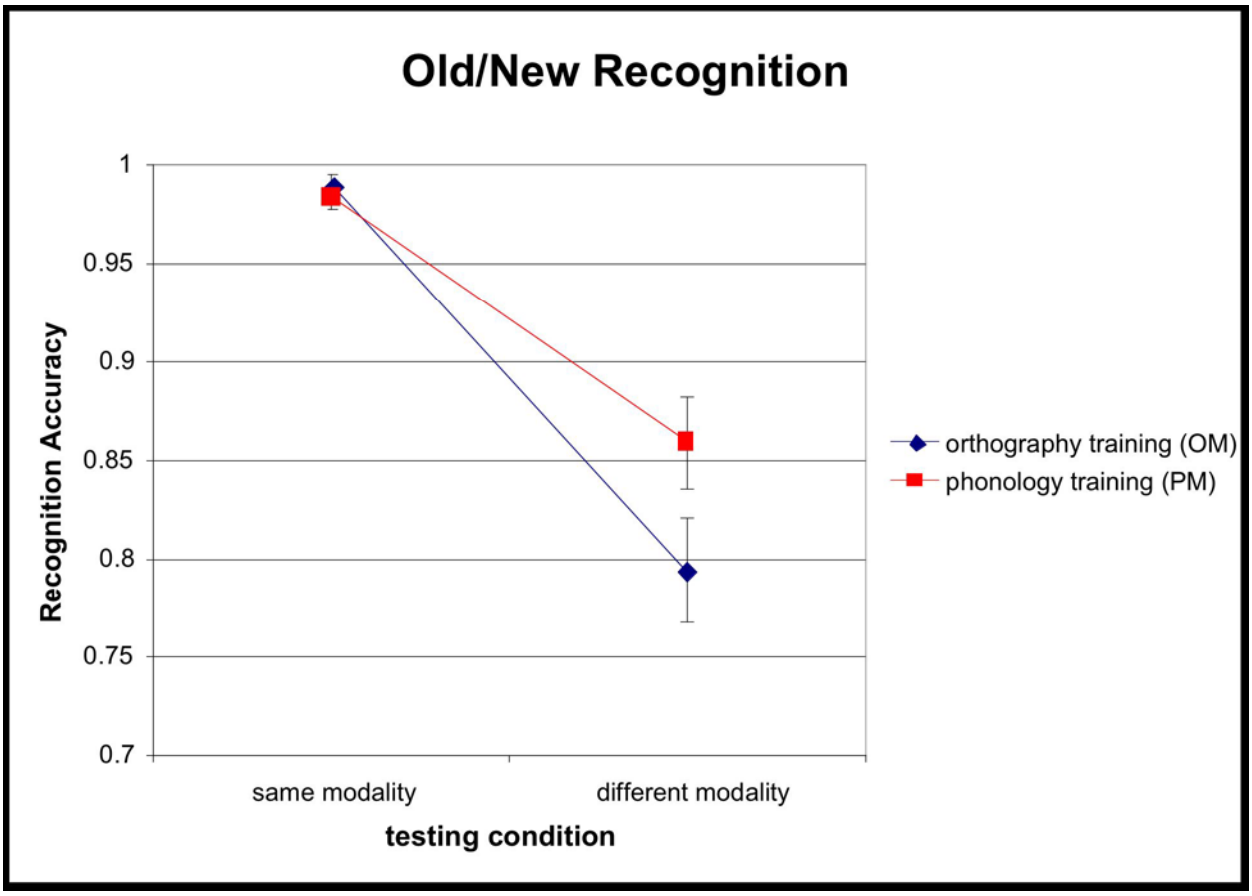

Figure 2: Mean recognition accuracy ± one standard error for words trained in the orthography-meaning and phonology-meaning training conditions, tested either in the same modality or different modality.

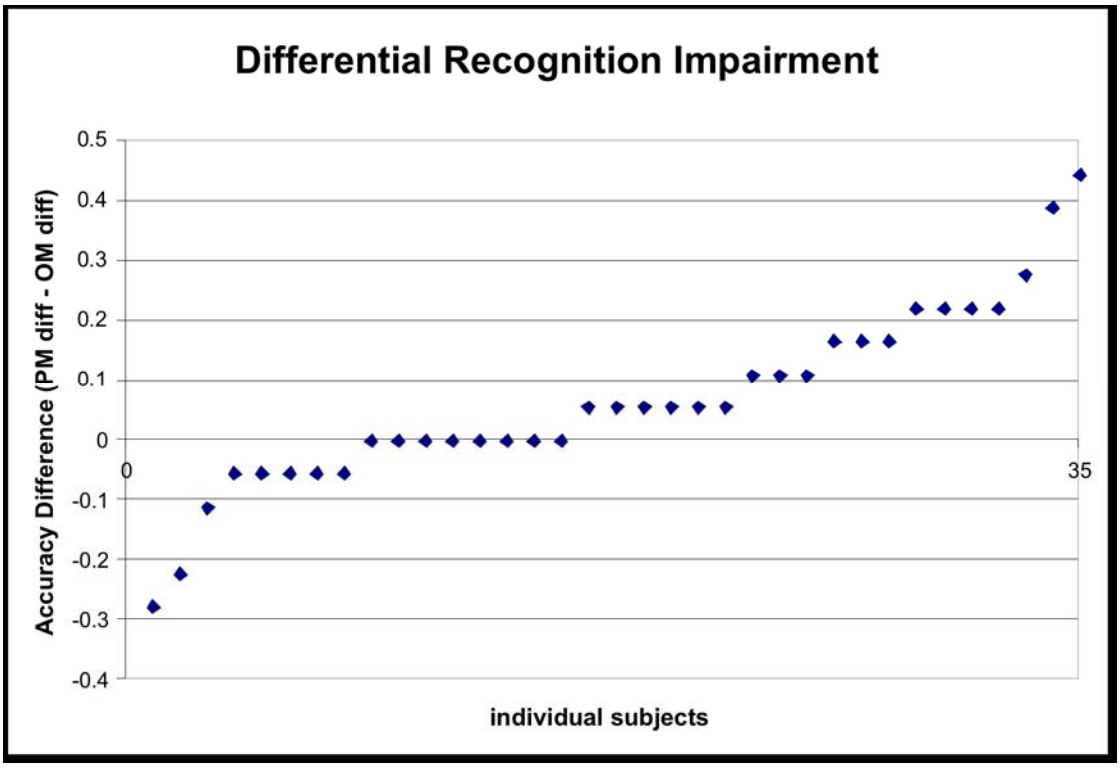

Figure 3: Accuracy differences for individual subjects between the two different-modality testing conditions, calculated by subtracting recognition accuracy for the orthography-meaning training from the phonology-meaning training in the different-modality testing condition. Positive values indicate participants are worse at recognizing words in the O-P condition than in the P-O condition.

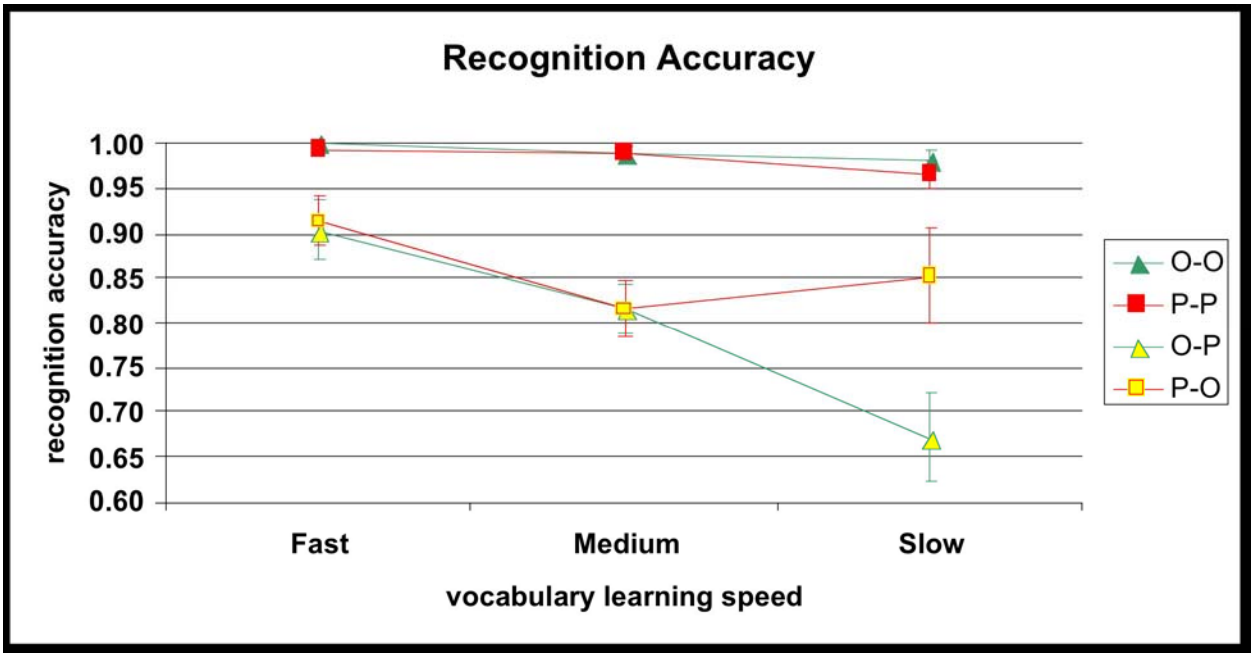

Figure 4: Mean recognition accuracy ± one standard error for the fast, medium, and slow learners.

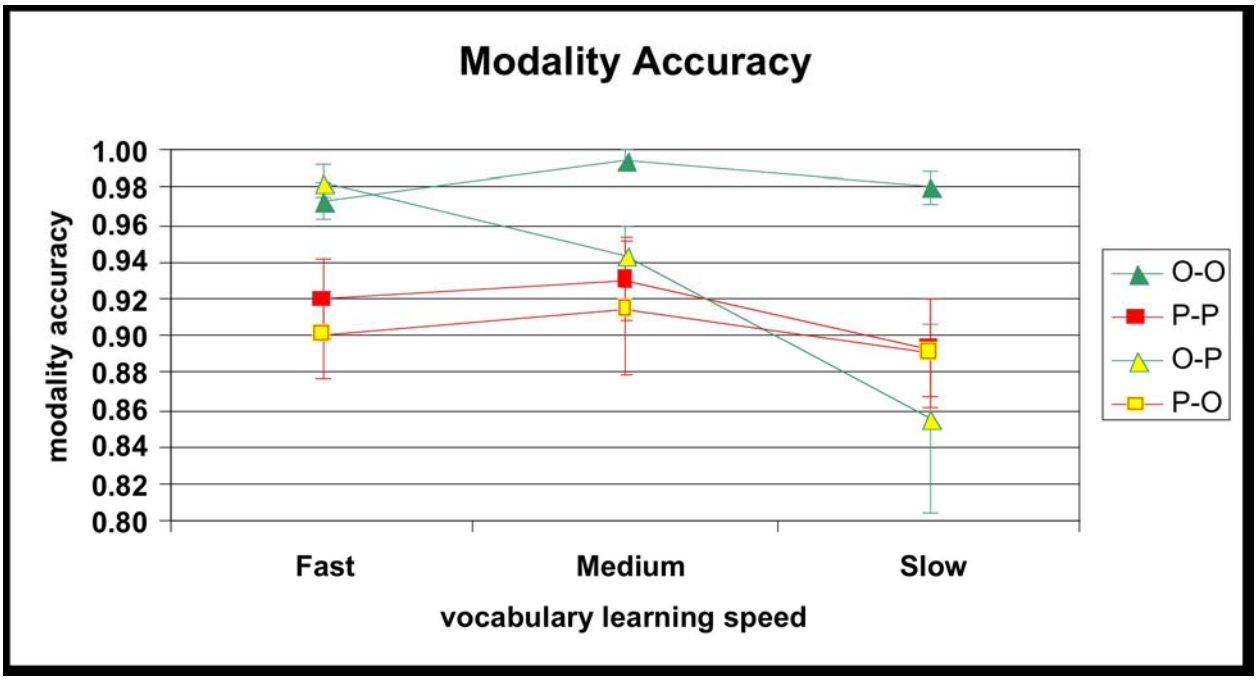

Figure 5: Accuracy in recalling the training modality of correctly recognized learned words.

APPENDIX A

Stimuli

ibex Wild mountain goat having large backward-curving horns

The ibex wandered freely throughout the African mountains.

onus A burden; an obligation

The onus was on the prosecution to prove the man had gotten sick because of his work environment.

bandy To toss or throw back and forth (especially words).

We bandied many words about when we tried to come up with a good title.

bawdy Humorously coarse; risqué. Vulgar, lewd.

The men sat around smoking and telling bawdy stories about their youths.

ambry In churches, a kind of closet, niche, cupboard, or locker for utensils, vestments, etc.

After the church service, the priest put the silver chalice back in the ambry.

wyvern A two-legged dragon having wings and a barbed tail.

The brave knight fought off the ferocious wyvern and saved the kingdom.

rivage A coast, shore, or bank.

She liked to wander along the green rivage in the spring, listening to the river.

myxoid Containing mucus; mucoid.

She had a myxoid cyst at the end of her finger.

xyloid Resembling wood; having the nature of wood

Wormwood is neither worm-shaped nor xyloid.

quahog An edible clam having a hard rounded shell

The restaurant used only the freshest quahogs to make their famous chowder.

ursine Of or characteristic of bears or a bear.

Because of its ursine appearance, the great panda has been identified with the bears; actually, it is closely related to the raccoon.

peruke A wig, especially one worn by men in the 17th and 18th centuries

In addition to wearing a peruke, Lord Wadsworth sold them to other men wanting long, flowing hair.

ulster A loose, long overcoat made of heavy, rugged fabric and often belted

It is appropriate to wear a dark ulster over a dinner jacket or tuxedo.

nebbish A weak-willed, timid, or ineffectual person.

He is a nebbish who might be played effectively by Woody Allen.

diptych An ancient writing tablet having two leaves hinged together.

Ancient Greeks used diptychs to practice writing.

vespine Of, relating to, or resembling a wasp.

Vespine nests can be located in many places.

glossal Of or relating to the tongue.

His glossal nerve had been severed leaving him with no feeling in his tongue.

gloaming Twilight; dusk; the fall of the evening.

He arrived at the village station on a wintry evening, when the gloaming was punctuated by the cheery household lamps.

quisling A traitor who serves as the puppet of the enemy occupying his or her country.

Hitler's plan was to use Cuesta as his Mexican quisling.

ultima Most remote; furthest; final; last; the last syllable of a word

They're travelling across Europe by train and are planning their ultima stop in Moscow.

xerosis Abnormal dryness, especially of the skin and eyes

She always had horrible xerosis in the winter and practically bought every bottle of lotion in the store.

yttrium a silvery metallic element

They learned in Chemistry class that Yttrium oxide has industrial uses like giving the red color hue in color television sets.

arcuate Having the form of a bow; curved.

The arcuate arteries are small curved branches of arteries supplying the brain with fresh blood.

pillory A wooden framework on a post, with holes for the head and hands, in which offenders w were formerly locked to be exposed to public scorn as punishment

As a punishment for adultery, she was locked in a wooden pillory for a week at the center of town.

zucchetto A skullcap worn by certain Roman Catholic clerics

One can tell the rank of a Roman Catholic cleric by the color of the zucchetto they wear on their head.

urticant Causing itching or stinging.

The sea anemone tenticles can be used to attack because of their urticant properties.

sibilant Of, characterized by, or producing a hissing sound like that of (s) or (sh).

The poet used lots of sibilant consonents in his poem about the snake.

cabochon A highly polished, rounded stone

The sapphire was cut like a cabochon for the ring.

badinage playful teasing; banter

The playful badinage of her coworkers made her office a fun place to work.

lacrimal Of or relating to tears.

Tears are formed in the lacrimal gland, which is located under the upper eyelid.

illation A conclusion, a deduction or inference

Faulty deductions or unimportant illations form a false image of things.

xylograph An engraving on wood.

She bought some beautiful xylographs to hang on her office wall.

assuasive Soothing; calming.

His assuasive remarks really helped the family in their time of need.

virgulate Shaped like a small rod.

The virgulate shape of the branch made a great makeshift stake that she substituted for the lost tent stake.

agog in eager desire; eager; highly excited She explored the deck of the ship, agog with excitement for her first trip.

unco So unusual as to be surprising; uncanny; extraordinary

He was a great traveling companion because of his unco sense of direction.

hinny The hybrid offspring of a male horse and a female donkey.

At first glance she thought the hinny looked like a donkey, but on closer inspection she decided the animal is more subtly like a horse.

alate Having winglike extensions or parts; winged

The alate seeds of the maple floated through the forest on the wind.

ramous Of or resembling branches.

Some cancers grow in a ramous fashion resembling tree limbs.

hubris Overbearing pride or presumption.

With dizzying hubris, Shelley elevated the purpose of the poet above that of priest and statesman.

afreet — A powerful evil spirit or gigantic and monstrous demon in Arabic mythology

To protect herself from the evil afreet, she wore a garlic necklace around her neck.

monish — To warn

His mother monished him of the consequences for driving without a seat belt.

legate — An ambassador or envoy

President Bush sent a legate to the Middle East to represent the United States at the peace talks.

piaffe — a cadenced trot executed by the horse in one spot

To win the equestrian match, John trained his horse to perform a fancy piaffe in front of the judges.

ersatz — imitation, fake, artificial

She wrote a letter full of ersatz sympathy to the coworker she never liked, who had just been fired.

clement — Inclined to be lenient or merciful; mild

The weather was particularly clement, so it was the perfect day for a walk in the park.

temblor — An earthquake

The temblor caused destruction throughout the city, and some could feel the tremor from miles outside of town.

younker — a young person (especially a young man or boy)

Jan has a three year-old younker and two older daughters.

vulpine — Of, resembling, or characteristic of a fox; cunning, clever

The vulpine predator lurked behind the trees preparing to attack his prey.

blandish To flatter with kind words or affectionate actions

She used her ability to blandish to her advantage anytime she wanted a raise at her job.

venial Forgivable, excusable, pardonable

Eating meat on a Friday is a venial sin, but murder is a mortal sin.

estival Of, relating to, or appearing in summer.

Jenny's family always liked to take an estival vacation in the Hampton's.

famulus A private secretary or other close attendant

In the late 1800's it was typical for rich families to have a famulus working in their home.

napiform Turnip-shaped; large and round in the upper part, and very slender below.

The plant had a napiform root, and the large upper part could be eaten.

oblation The act of offering something, such as worship or thanks, especially to a deity

The priest reminded everyone to offer their oblation throughout the week, not just on Sundays.

kyphosis Abnormal rearward curvature of the spine, resulting in protuberance of the upper back; hunchback

The hunchback of Notre Dame had severe kyphosis.

refluent Flowing back; ebbing.

The tide is refluent so we'll soon be able to walk further down the beach.

vesicate To blister or become blistered

Her feet vesicated after wearing ill-fitting high-heeled shoes all day.

bibulous Of, pertaining to, marked by, or given to the consumption of alcoholic drink.

After each weekend, the bibulous can be found hungover, holding their heads and wearing their sunglasses.

hebetude Mental dullness or sluggishness.

Some say that too much television is leading us toward a nationwide hebetude.

intarsia A decorative inlaid pattern in a surface, especially a mosaic worked in wood

To construct an instarsia, outline drawings are used as templates for cutting the many pieces of wood.

kilderkin A cask;A small barrel; an old liquid measure containing eighteen English beer gallons, or nearly twenty-two gallons

The tavern kept its beer supply in kilderkins behind the bar.

chaparral A dense thicket of shrubs and small trees

Once she lost her necklace in the chaparral she knew she would never see it again because it was too dense to look through.

girandole an ornate candle holder; often with a mirror

She said that the antique girandole hanging on the wall is also known as a 'mirror chandelier'.

yagi a sharply directional antenna

John adjusted the yagi on his television because he wanted better reception of the football game.

junto A small, usually secret group joined for a common interest.

Chris joined the junto in hopes of meeting other star trek aficionados.

yenta A person, especially a woman, who is meddlesome or gossipy

The yenta was famous for knowing the latest rumors in town.

natant Floating or swimming in water

She wanted to get some natant plants for the pond she dug in her yard.

salver A tray for serving food or drinks.

She put the drinks on the salver and headed out the kitchen to serve them to her guests.

cygnet A young swan.

The young cygnet was swimming closely next to his swan mother.

schism A separation or division into factions.

The schism between East and West Germany ended when the Berlin Wall came down.

dandle To move (a small child) up and down on the knees or in the arms in a playful way; to p pamper or pet

It is an old wives' tail that if you don't dandle your baby on your lap, he or she will get fat.

kittle Touchy; unpredictable.

Because of her kittle personality, her friends never knew what to expect from her when they spent time together.

garboil Confusion; uproar.

To avoid garboil, the twins never wore the same clothes.

flivver An automobile, especially one that is small, inexpensive, and old

John decided to buy a new car after his old flivver broke down on the highway.

wheedle to entice by soft words; to cajole; to flatter; to coax; to gain or get by flattery or guile

The school was always trying to wheedle contributions from the parents by telling them how bright their children were.

yashmak A veil worn by Muslim women to cover the face in public

In some Middle Eastern countries, women who do not wear their yashmaks in public can be arrested by the police.

lambaste To give a thrashing to; to beat severely; To scold sharply; to attack verbally; to berate.

The politician spent most of his campaign money lambasting his opponent, rather than discussing the issues.

xanthous yellow; having light brown or yellowish skin.

The xanthous coloring of her skin suggested she contracted jaundice.

zydeco Popular music of southern Louisiana that combines French dance melodies, elements of Caribbean music, and the blues, played by small groups featuring the guitar, the accordion, and a washboard

They could tell the carnival celebration was about to begin when the zydeco melodies were heard several street blocks away.

uranic Of or relating to the heavens; celestial.

It is an uranic principle that performing evil acts will bring punishment to the evil-doer.

jubilee A season or an occasion of joyful celebration

Jessica was enjoying the celebrations of the annual spring jubilee with her family.

bivouac An encampment for the night usually without tents or covering

Our troops retreated for the night and went into the bivouac

venatic Of or relating to hunting.

John always liked venatic sports such as deer and duck hunting.

abeyant temporarily inactive

The plan was abeyant until we could get further funding.

gravamen The most important part of a complaint

In the accident lawsuit, the gravamen was the negligence of the driver.

pluvious Characterized by heavy rainfall; rainy

The pluvious weather lasted for days, causing a devastating flood throughout the small town.

maculate Marked with spots, blotched

Her white scarf was maculate after dropping it in the muddy puddle.

zecchino sequin; a spangle often sewn on cloth

Mary was wearing a beautiful dress with golden zecchinos that sparkled.

folderol Foolishness; nonsense

Her silly comments and folderol discredited her ability to serve as governor.

cerulean Azure; sky-blue

The cerulean skies were mesmerizing to Pittsburghers who see gray cloudy skies most of the year.

grimalkin a cat, especially an old female cat; an old woman considered to be ill-tempered

The irritable grimalkin would not play with the other cats because she was too old to run around the house.

heptarchy A government by seven persons; also, a country under seven rulers

The local government rid itself of heptarchy because of the many disagreements between the government officials.

frisson A shudder of excitement

As we descended from the pinnacle of the rollercoaster track we experienced a short frisson of excitement.

prescient Foresight or knowledge of what will happen

His prescient that the Buccaneers would win the Superbowl was correct.

chafferer A vendor who enjoys talking while making a sale; a bargainer

Most street vendors are chafferers by nature because they like to sell their merchandise at the best price.

leister A three-pronged spear used in fishing.

Native Americans used leisters to catch their fish long ago.

vilipend To treat something as if it has little value, to express a low opinion of

He thought I vilipended his effort, but in actuality I appreciated his work very much.

paranymph the bridesmaid conducting the bride to the bridegroom

The bride has one chief paranymph that helps her with the wedding plans, she is also known as the maid of honor

solleret a flexible steel shoe forming part of a medieval suit of armor

During battle, the knights kept their feet protected with steel sollerets.

roorback A false or slanderous story used for political advantage

Politicians use roorbacks to defame the name of their opponents.

fossick To search for gold in abandoned claims or to rummage around for anything valuable

The homeless tend to fossick through trash hoping to find something they can use.

pintle A hook or a bolt on the rear of a towing vehicle for attaching a gun or trailer; a pin or a bolt on which another part pivots

The rusty pintles must be replaced soon before they snap causing the door to fall off the hinges.

beleaguer To harass; annoy persistently

The other children beleaguered the boy because of his lisp.

solfeggio A singing exercise using the syllables do, re, me, fa, so, la, ti

Singers use the solfeggio exercise to warm up their vocal cords before they start singing.

Untrained Words

baize

caitiff

cullion

demiurge

dharna

dithyramb

dunnage

gudgeon

higgle

hircine

kevel

logorrhea

lorgnette

muzhik

novercal

oubliette

ovine

oxter

qiviut

recuse

rugulose

sororate

sparge

tomalley

tomentose

urticate

uxoricide

vaunty

viaticum

vibrissae

yataghan

zori

triturate

peripatetic

escutcheon

chelonian

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