INDIVIDUAL DIFFERENCES IN REPRESENTATIONS OF NEWLY LEARNED WORDS: AN EVENT-RELATED INVESTIGATION

by

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Adults of varying comprehension skill were trained on a set of previously unknown rare English words (e.g. *gloaming*) in three different learning conditions which manipulated the type of word knowledge that participants learned about the words. Trained words were presented in one of three conditions: (1) Orthography- to- Meaning (no phonology); (2) Orthography- to- Phonology (no meaning); and (3) Phonology- to- Meaning (no orthography). Following training, participants made meaning judgments about the trained words in addition to familiar known words and untrained rare words while their ERPs were recorded. Behavioral results showed no significant differences of comprehension on meaning relatedness task performance. ERP recordings segmented after the presentation of the first word indicated skill differences in amplitude and latency for N400 and P600 components. Less skilled comprehenders showed larger N400 effects for phonology to meaning trained words than high skilled comprehenders indicating that they were not successful at making an orthographic representation from phonological information that was given in training. P600 results indicated that low skilled comprehenders showed no specific episodic effects for trained words versus untrained words, while high skilled comprehenders showed a modified P600 'old/new' effect for rare words versus known words. These results demonstrated that ERPs provide distinctive information about how newly- learned words are represented, and how these new representations differ with individual differences in comprehension skill.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. Introduction

Vocabulary is associated with a wide range of cognitive outcomes, especially having an impact on general comprehension. As noted in the literature review to follow, general vocabulary learning and word knowledge are highly variable and are associated with individuals' reading ability. Here, ***word knowledge*** is defined as having information about a word's pronunciation and spelling, and being able to retrieve the meaning of this word and use it correctly in context. Many behavioral studies have established the consequences of differences in word knowledge on meaning retrieval, phonological processing, inference making, and general comprehension. The goal of this study was to establish the consequences of different types of word training environments which manipulated available word knowledge (semantic, phonological, and orthographic) for a particular word on how this new word was learned in adults of varying comprehension skill. In particular, this study was aimed at extending current behavioral results on word knowledge and vocabulary learning by integrating a neuropsychological methodology like Event-Related Potentials (ERPs) that provided information about the time course of new word learning in conjunction with behavioral measures. The benefit of using ERP methodology to study word learning is the ability to study the time course of word processing. In the study reported here, we used ERPs to provide time course information on how different word training environments which provided incomplete word knowledge for rare English words affected later meaning judgment of these words in adults of varying comprehension skill.

Our interest in this study was to examine how incomplete word knowledge available for a newly learned word will affect how is it processed at a later encounter (e.g. during a meaning

judgment task). The consequences of having incomplete word knowledge about a word are two-fold: first, behaviorally, we would observe that the ease of making a decision about the learned word will depend on the information that the individual knows about the word, and second, the time course of word identification and meaning retrieval will be affected when the necessary information to process a word is not available. This is where ERPs may be helpful in revealing the outcomes of incomplete word knowledge on the time course of word identification for newly learned words.

As mentioned earlier, general vocabulary learning is highly variable and is correlated with comprehension skill. So, examining how comprehension skill influences new word learning is an important factor to consider. Many studies have shown that comprehension skill is an important component in word level processing. For example, according to the Lexical Quality Hypothesis, normal readers' lexical representations vary in quality across words (e.g. whether they are fully specified orthographically, phonologically, and semantically), consequently leading to variations in word knowledge. For example, one may know how to pronounce the word "*gloaming*" but may not be able to retrieve its meaning. Furthermore, lexical representations vary across individuals (i.e. skilled readers versus less skilled readers), with less skilled readers have fewer fully specified lexical representations than skilled readers. Already existing differences in word knowledge and ability to establish complete representations for words may influence new word learning when the learning episode for the word is impoverished. Also, beyond lexical quality, numerous studies have noted that poor readers have smaller vocabularies than good readers (as reported in Daneman, 1984). Others have reported that the variability in comprehension ability can be predicted simply by vocabulary scores (Everatt & Underwood, 1994). Given that comprehension skill is strongly correlated with already existing

lexical quality and word knowledge, it is an important factor that we will consider for the current study.

Other behavioral evidence has shown that reading ability is not only correlated with existing word knowledge, it also has an influence on the ability to learn new words. For example, Hogaboam and Perfetti (1978) have shown that comprehension skill is associated with unfamiliar word decoding ability. In their training study with children, skilled readers benefited more from minimal aural exposure of a word than did the less skilled readers. Specifically, for the skilled readers hearing the word in training was enough to allow them to read it the first time they saw it, but the less skilled readers did not benefit from hearing it, they also had to see the word with aural exposure. Others have found that skilled readers are more efficient and likely to activate phonology in such tasks as lexical decision and phonological lexical decision than less skilled readers (Unsworth & Pexman, 2003). Reading ability is further implicated in other processes such as learning new vocabulary in context. For example, according to the *learning-from-context hypothesis*, vocabulary and comprehension are correlated because both reflect the individuals' ability to learn or acquire new information from text (Daneman, 1984). Individuals with large vocabularies have been successful at inferring word meanings from reading and listening, and are able to incorporate already known word knowledge to help themselves learn new words. Thus, word knowledge is partially a product of reading ability. Also, these findings have been extended to show that good readers appear to be more word-conscious and thus better able to acquire new vocabulary than poor readers (Davy, 1987). Breadth of word knowledge plays an important role in reading comprehension; the more word knowledge a reader has increases the number of high quality lexical representations that are fully specified, and these

fully specified lexical representations lead to more efficient comprehension, and thus, to more opportunities to learn new words.

This behavioral evidence on the association between word knowledge, vocabulary learning and comprehension skill gives us a reason to believe that individual differences in comprehension skill will influence new word learning. Further, in the case of when incomplete word knowledge is available for a newly learned word, we can hypothesize those individuals with more word knowledge (i.e. skilled comprehenders) will make use of their knowledge in conjunction with available information from word training to try to fully specify a representation for a new learned word.

To examine influences of comprehension skill on new word learning, ERPs prove to be helpful in providing time course information about the processing of newly learned words, and how this time course may differ as a function of comprehension skill. Individual differences in comprehension skill have been already been shown to be associated with differences in amplitudes and latencies of different ERP components for word processing (Rüsseler, Pobst, Johannes, & Münte, 2003; Rubin & Johnson, 2002; Coch &Holcomb, 2003). This study aims to extend current results in the literature to find ERP components that are associated with new word learning. While there have not been many studies directly linking ERP components to word learning, the current literature for word processing and ERPs suggests two major classes of ERP components that are relevant for the current experiment; they are reviewed briefly here.

The first class of components includes early markers indicative of phonological and orthographic processing. The N200 has been shown to be sensitive to orthographic stimuli (Kramer & Donchin, 1987; see also Liu & Perfetti, 2002). Studies of English and Chinese reading have shown this early component of orthographic processing at 200 ms and a slightly

later component for frequency effects at 250 ms (Liu & Perfetti, 2002). Other studies have shown later negative components like the N320 and N350 that have been linked to processing of pronounceable real words and phonologically legal stimuli (Bentin, Mouchetant-Rostaing, Giard, Echallier, and Pernier, 1999). Earlier ERP markers for form processing and word frequency effects have been reported at 132 to 170 ms post stimulus onsets (Sereno, Rayner, & Posner, 1998; Dehaene, Naccache, Cohen, Le Bihan, Magnign, Polie, & Riviere, 2001). In the current experiment, we expected observe these ERP components to indicate form processing and sensitivity to word frequency.

The second class of ERP components includes negative peaks at about 400 ms (N400) and positive peaks at around 600ms (P600). These components are linked to semantic processing and episodic memory effects. The N400 has been shown to be related to individuals' semantic and task-relevant expectations (Kutas & Van Petten, 1994). In sentence contexts (Kutas and Hillyard, 1980) and single-word presentation (Nobre & McCarthy, 1994), words that are incongruent with previous contexts produce a negative component that peaks approximately about 400 ms (N400) after the onset of the word, while a congruent word produces a reduced N400 effect. Rüsseler et al. (2003) also have shown reduced N400 effects for 'old' words which participants have seen prior to completing old/new item decision task on a previously learned list of words. For the current study, we predicted that words previously seen in training would produce reduced N400 effects relative to words that participants did not see in training. For the current experiment, we were also interested in later components than the N400, like the P600 which peaks at approximately 600 ms post stimulus presentation. In the language literature, the P600 has been mainly observed in the syntactic processing as an indicator of syntactic and semantic incongruity (Osterhout & Holocomb, 1992). However, in the memory literature, P600

has been observed for episodic memory effects (Paller & Kutas, 1992). Specifically, in memory retrieval tasks, ERP's are more positive to 'old', previously encountered words than to 'new ' words that had not been seen before from about 300 to 800 ms following the onset of the word (Curran, 1999; Rugg, Mark, Walla, Schloerscheidt, Birch, & Allan, 1998; Allan, Wilding, & Rugg, 1998). This late component is also referred to as P600 'old/new' effect and is a marker for an episodic memory trace. For the current experiment, we expected to observe a P600 effect positivity for words that individuals encountered in word training compared to words that were not trained.

There are a few studies with dyslexic, learning disabilities, beginning, and adult low-comprehension individuals that have shown these ERP components to differ in amplitude and latency in comparison to normal readers. Low- ability beginning readers lack a substantial N400 effect for words that are normally observed for normal readers in the same age group (Coch & Holcomb, 2003). Further, in studies of learning disability individuals, significantly longer N400 latencies were found in parietal electrode sites for semantic processing (Rubin and Johnson, 2002). Others have not found these N400 effects for dyslexic readers, but have noted that dyslexic readers fail to show P600 'old/new' effect for previously encountered high and low frequency words (Rüsseler, et al., 2003). These results have been replicated by Perfetti, Wlotko, and Hart (submitted, 2004) who taught skilled and less skilled comprehenders rare words, and found that skilled readers showed more pronounced episodic effects (P600) for words that were previously encountered in training, and more pronounced N400 effects for words whose meanings were incongruous with learned words.

Combined with the ERP indicators noted here, the training manipulation for this study also aids in examining the research question of how existing and new word knowledge affects

new word learning. In the experiment reported here, college students of varying comprehension skill learned unfamiliar rare English words. The word training paradigm was designed to isolate the constituents of a word (i.e. phonology, orthography, and semantics), thereby only training partial word knowledge for each word. In particular, our training protocol had three separate conditions. For each of the three training conditions no more than two constituents of each word were presented to the participant. Specifically, in the ***orthography-meaning*** (ignoring phonology) condition, subjects were trained on the spelling and meaning of a word, and never heard the pronunciation of the word. In the ***orthography-phonology*** (ignoring meaning) condition, participants were trained on the spelling and the pronunciation, but did not learn the meaning. Last, in the ***phonology-meaning*** (ignoring orthography) condition, subjects were trained on the pronunciation and meaning of a word, and did not see the spelling of the word.

Following the completion of training, participants were tested on the extent of their word learning using a meaning- relatedness judgment task. Participants were presented with a pair of words such as "***gloaming***" (a trained word) followed by "***dusk***" or "***turnip***" (a word related in meaning or unrelated in meaning), to which they had to make the appropriate response of whether or not the words have the same or different meaning. A simple meaning relatedness judgment task using all of the trained words was sufficient for ERP recording since we were interested with what occurs when the participants see the trained word (the stimulus) that they have just learned.

We hypothesized that, following word training, when participants see a trained word we should observe differences in early components related to orthographic and phonological processing. Specifically, differences in frequency between rare words and known words should elicit differences in early orthographic and phonological processing components. For later

components, we hypothesized reduced N400 effects for words that were learned in training since participants have seen them prior to the task. If our participants were successful at decoding orthographic information during training of ***phonology-meaning*** words, then N400 effects will also be reduced for words trained in this condition. This prediction is an extension of the Rüsseler et al. (2003) findings for which single word presentation for previously seen words produce reduced N400 effects. Also, we predicted to observe ERP evidence that the participants had become familiar with the words learned by way of P600 episodic marker for trained words compared to words that were not in training. Based on evidence from individual differences, we expect that low- skilled comprehenders would not be as effective in learning the new words and would not be able to supplement missing word knowledge from word training with their own word knowledge, and that this would be reflected in differences in ERP components for both early form processing, and later recognition processes.

2. Methods

2.1. Participants

Thirty seven native English speakers for this experiment were recruited from the University of Pittsburgh Department of Psychology Undergraduate subject pool. These individuals were invited from a larger pool of potential participants who had previously completed a comprehensive lexical and comprehension battery. Of these participants, 10 were high-skilled readers, 12 were medium-skilled readers, and 15 were low-skilled readers. Their comprehension skill was determined from performance on the Nelson-Denny comprehension test (Nelson & Denny, 1973). Both number of items answered correctly and number of items (out of 36) tried were considered for the total comprehension score. Participants received one point for each item they answered correctly and were deducted 0.25 of a point for each item answered

incorrectly. Using this method, both accuracy and speed could be accounted in the comprehension score. High- skilled readers scored in the upper third of the distribution, with an average comprehension score of 27.9; middle- skilled readers had scores from the middle third of the distribution, with a mean score of 23.12; and low-skilled readers had scores ranging in the bottom third of the distribution, with a mean score of 16. 43. Upon completion of the experiment, individuals were compensated $7/hour for the training session and $10/hour for the ERP portion of the study.

2.2. Materials

The full stimuli set for this experiment is in Appendix A. The materials included a total of 210 words. 105 of the rare words were used in the word training and were randomly assigned to each of the three training conditions. The set also included 35 untrained rare words, 35 familiar known low- frequency words, and 35 filler items. All words were four to eight letters long, and two to three syllables. Rare word frequency was less than 1 per million, and most words were not in the Kŭcera and Francis (1967) corpus. The familiar known items had a frequency rating of less than eight words per million.

2.3. Training

Participants completed three training blocks during the behavioral training portion of the experiment. They were randomly assigned to the order of which the conditions appeared. In the ***meaning-orthography*** (ignoring pronunciation, OM condition) condition they were presented with a rare word and they were given its definition and an example sentence that used the word in context. In the ***orthography-phonology*** (ignoring meaning, OP condition) condition, subjects

were presented with the rare word and they heard its pronunciation, no definition or example sentence was presented. Lastly, in the ***phonology-meaning*** (ignoring orthography, PM condition) block, they heard a rare word pronounced and were presented with the definition and an example sentence. To prevent the subjects from seeing the spelling of the rare word in the last condition, the example sentence was presented with a blank where the word would have appeared. At no point in this condition (PM) do they learn the spelling of the word. All rare words in the training set were randomly assigned to each of the three training conditions.

These are examples of sample context sentences:

Meaning-Orthography
For the rare word ***assuasive***

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

Phonology-Meaning
For the rare word ***bawdy***

The men sat around smoking and telling ___ 👂 ___stories about their youths.

(👂 = the participant will hear the word 'bawdy' pronounced)

Participants were instructed that they have two hours to learn all 105 test words. The word training session proceeded in two phases; a learning phase and a testing phase. In the learning phase, the participant studied the words' meaning or pronouncing at their own pace. They proceed through all of the training conditions once, and were asked to judge their familiarity with the words by pressing the appropriate keys ('1' for familiar, '2' for unfamiliar). Participants had four seconds to make their familiarity decision for each word. Once they judged the word's familiarity, they had as long as they needed to study the meaning or pronunciation of the rare words. Once the learning phase was completed, the participants were tested on their knowledge of the newly studied words with an experimenter. The experimenter cycled through

each of the conditions with the participant and rated whether the individual correctly retrieved the meaning or pronunciation depending on the training condition type. They received feedback on the correctness of their response. Regardless of their response, subjects were able to study the word, meaning, or pronunciation after their responses had been recorded. The subject received one chance every testing cycle to retrieve the appropriate meaning or pronunciation of the word. If the meaning or pronunciation was correctly retrieved in two testing cycles in a row, then that word was regarded as learned and did not appear again. This procedure continued until all the words are learned. A 100% learning criterion was used for all participants. They had to retrieve all appropriate meanings and pronunciations for the words correctly twice in a row before participating in the post-training semantic judgment task.

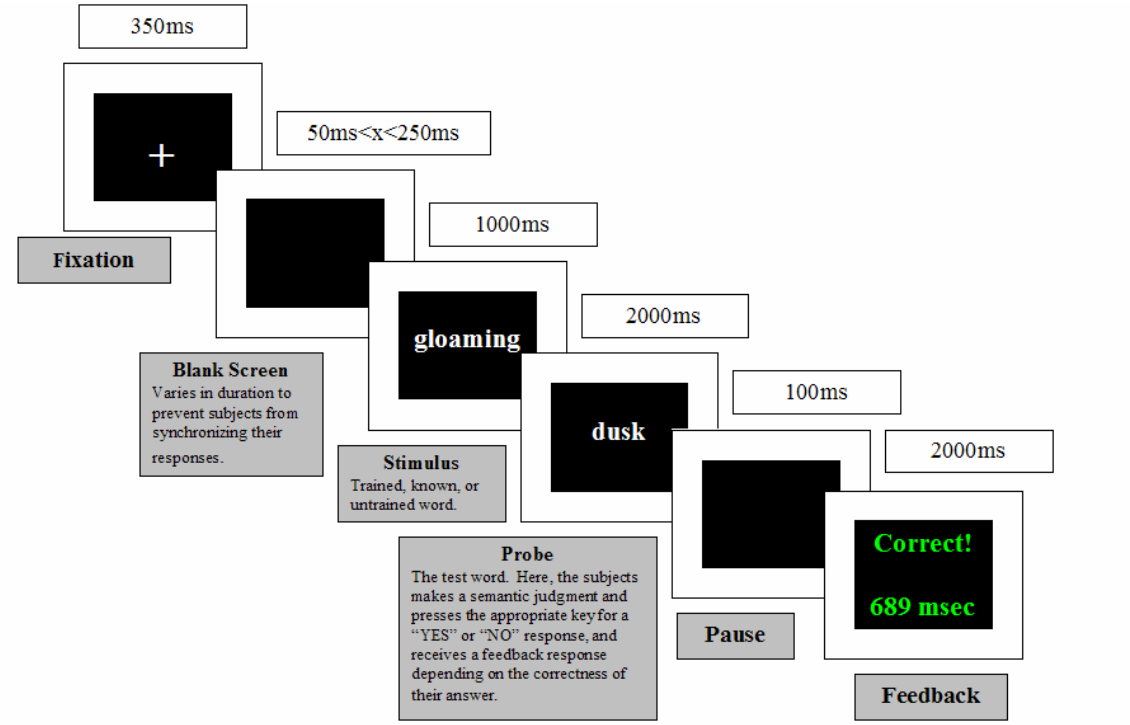
2.4. Post Training Semantic Relatedness Task

After the training period, participants completed a semantic relatedness judgment task while their EEGs were recorded. Each trial began with a fixation cross that remained in the middle of the computer screen for 350 milliseconds. Following the fixation, participants saw a briefly presented blank screen that varied in duration from 50 to 250 milliseconds. The variability in duration of the blank screen was to reduce any influence of non-stimulus related time-locked electrical activity. Following the blank screen, a stimulus word was selected randomly from the total set of words (words trained in the OM, OP, or PM conditions, known words, untrained rare words, and filler items), and was presented for 1000 milliseconds. Immediately, the presentation of the meaning probe word followed and was presented for a maximum of 2000 milliseconds. On half of the trials, the probe word was semantically related to the stimulus word, ("YES" trials) and on the other half the trials the probe word was unrelated

("NO" trials) to the stimulus. The semantically related pairs were created based on the experimenters' judgment, and were not necessarily derived directly from the definition the participant studied during training. Semantically unrelated pairs were created by shuffling the probe word pairs of the stimulus words, and randomly making new pairings. The order of the stimulus word presentation and probes was randomized for each participant. Each participant completed a total of 210 trials while their ERP's were recorded.

Participants were instructed to press the '1' key with their right index finger if the two words presented were related in meaning and to press the '2' key with their right middle finger if the two words were unrelated in meaning. The meaning probe word was removed from the screen when a response was made, or if no response was made after 2000 ms elapsed. Participants received feedback on the correctness of their judgment after each trial. If the participant was correct, 'correct' in green font color and the time it took them to make the decision was displayed on the screen for 2000 milliseconds prior to the onset of the next trial. If the response was incorrect, 'incorrect' in red font color was displayed, but with no decision time duration. The stimulus presentation protocol is illustrated in Figure 1.

Figure 1 Stimulus Presentation Protocol



To minimize eye-movements and eye-blinks during EEG recording, participants received a "blink break" every 48 trials to rest their eyes. The duration of this break was controlled by the participant; once they were ready to continue with the experiment, they pressed the space bar.

2.5. ERP recording

Prior to beginning the post-training semantic relatedness judgment task, participants were fitted with the electrode cap. Scalp potentials were recorded from a 128 sites using a Geodesic Sensor Net (Electrical Geodesics, Eugene, OR) with Ag/AgCl electrodes. All impedances were kept under 40KΩ. A vertex reference was used in the recording, and the data was recomputed

off-line against the average reference. Six eye channels allowed rejection of trails with eye movement and eye blink artifacts. The EEG signals were recorded with a sample rate of 1000Hz. The hardware filter was between 0.1 and 200Hz. A 30 Hz lowpass filter was applied to all participants' data. ERP's were stimulus -locked and averaged over a 1100 millisecond time segment; a 100 millisecond baseline and an 1000 millisecond epoch defined only by the presentation of the stimulus (the first word). Bad channels were removed from the recordings and replaced by spherical spline interpolation using data from the remaining channels. Any trials containing eye-movement, eye blinks, or channel artifacts were removed and not used in analysis. For each participant, no more than five trial segments were rejected due to eye-movement or eye blinks. If too many trial segments (> 5) were bad due to eye-movement artifacts, the participant's data were excluded from the analyses. There were five such participants (1 middle comprehender and 4 low comprehenders); their data were not included in the ERP analyses. Following trial rejection, ERP's were transformed using average reference, and then corrected using a 100 millisecond baseline.

3. Results

3.1. Behavioral Data

3.1.1. Reaction Time Data

For these data, a 5 x 2 x 3 mixed factorial ANOVA with Word Type (OM, OP, PM, known, and untrained rare) and Relatedness ("YES" or "NO" response) as the two within subject factors, and with comprehension Skill (high, middle, low) as the between subjects factor. Three low skilled subjects were excluded from the analyses due to incomplete training sessions. In the analysis, only correct trials were considered, except for reaction times for the OP and the untrained rare conditions for which both incorrect and correct trial reaction times were included.

For the OP and untrained word conditions, reaction times were not statistically different for incorrect versus correct trials. For OP trials, t (33) = -.527, p = .602, with a mean of 842.38 ms for incorrect trials and 848.84 ms for correct trials. For rare untrained words, t (33) = -1.044, p = .304, with a mean of 841.39 ms for incorrect trials and 853.81ms for correct trials. Accuracy for these trials was not significant than chance (see accuracy data below), consequently, excluding the incorrect trials for these conditions would only allow half of the data to be used in the analysis, while for other conditions, more than 80% of the trials were correct. For statistical considerations, both incorrect and correct reaction times for the OP and rare untrained conditions were included in the analysis.

Table 1 shows decision time results for the meaning relatedness judgment for each of the skill groups.

Table 1 Behavioral Results: Semantic Decision Times (in milliseconds)

Condition	**Skill**			
	High	Middle	Low	*Mean*
OM Related ('YES')	627.27	678.31	731.87	680.15
OM Unrelated ('NO')	695.56	730.14	771.41	732.37
Mean	661.42	704.22	753.14	**706.26**
OP Related ('YES')	810.19	836.87	869.87	838.98
OP Unrelated ('NO')	822.35	834.19	887.33	847.96
Mean	816.27	835.53	878.60	**843.47**
PM Related ('Yes')	715.98	739.32	768.61	741.31
PM Unrelated ('No')	760.99	758.54	832.24	783.92
Mean	738.49	748.93	800.43	**762.62**

Known Related ('YES')	711.23	740.65	752.39	734.76
Known Unrelated ('NO')	738.14	804.83	783.28	775.42
Mean	724.68	772.74	767.84	**755.08**
Untrained Related ('YES')	853.81	834.68	877.81	855.43
Untrained Unrelated ('NO')	826.56	844.67	856.62	842.61
Mean	840.18	839.67	867.21	**849.02**

Results indicated significant main effects for Word Type, $F(4, 124) = 48.55$, $p < .01$, and Relatedness, $F(1, 31) = 14.14$, $p < .01$, but no significant effect for Skill, $F(2, 31) = 0.763$, $p = 0.475$. Rare untrained words yielded the slowest reaction times but were not significantly different than OP trained words. For the main effect of Relatedness, participants were faster on "YES" trials ($\underline{M}$= 770.13 ms) than "No" trials, ($\underline{M}$ = 796.46 ms).

For the interaction of Word Type x Relatedness, $F(4,124) = 4.704$, $p < .01$, participants were faster for "YES" trials than "NO" trials for the OM and known conditions. Participants did not show any reaction time differences for relatedness for OP, PM, and untrained rare trials. The three-way interaction was not statistically significant.

3.1.2. Accuracy Data:

Another 5 x 2 x 3 mixed factorial ANOVA with Word Type and Relatedness as the two within subjects factors, and comprehension Skill as the between subject factor was completed for the accuracy data. Table 2 shows the accuracy results for the meaning relatedness judgment task.

Table 2 Behavioral Results: Percent Accuracy

Condition	Skill			
	High	Middle	Low	*Mean*

OM Related ('YES')	91.1	86.3	89.2	88.8
OM Unrelated ('NO')	86.9	84.8	81.6	84.4
Mean	89.0	85.6	85.4	**86.6**
OP Related ('YES')	44.2	39.6	37.8	40.6
OP Unrelated ('NO')	71.9	77.9	72.1	74.0
Mean	58.1	58.8	54.9	**57.3**
PM Related ('Yes')	79.3	78.9	74.8	77.6
PM Unrelated ('No')	81.2	82.4	78.5	80.7
Mean	80.2	80.6	76.6	**79.2**
Known Related ('YES')	94.7	86.2	84.2	88.7
Known Unrelated ('NO')	89.7	90.3	83.5	87.8
Mean	92.2	88.3	83.8	**88.1**
Untrained Related ('YES')	33.9	26.1	29.4	29.8
Untrained Unrelated ('NO')	77.4	81.8	78.9	79.4
Mean	55.6	53.9	54.2	**54.6**

ANOVA showed significant effects of Word Type, $F(4, 124) = 161.975$, $p<.01$, Relatedness, $F(1, 31) = 36.002$, $p < .05$, and Word Type x Relatedness interaction, $F(4, 124) = 47.330$, $p < .05$. No significant effects of skill were observed. The performance on the OP and Rare trials as expected was the worst ($\underline{M}$ =57.3 % and $\underline{M}$ = 54.1%). Participants were overall less accurate on "YES" trials, ($\underline{M}$ = 65.1%) than they were on "NO" trials ($\underline{M}$ = 81.3%). The Word Type x Relatedness interaction indicated that participants have a 'no' response bias for OP condition trained words and Untrained Rare trials. The data in Table 2 data show a tendency across all skill groups to judge the OP and Untrained Rare words and their meaning probes as

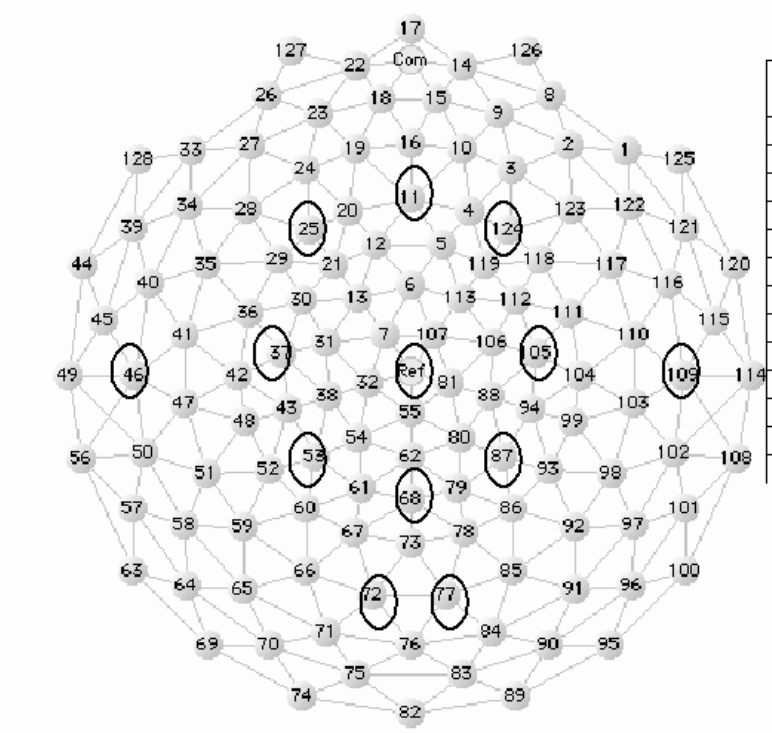
unrelated as indicated by the high accuracy scores for "NO" trials (M= 74.0% for OP and M= 79.4% for Untrained Rare) for these experimental conditions.

It was our expectation that performance on the OP and Untrained Rare trials would be at chance (~50%) because the participants did not learn the meanings for these words; they did not enough information about the words to judge relatedness of the stimulus and the meaning probe. To statically verify that this was the case, a series of post-hoc t-tests were performed on the accuracy data for the OP and the Untrained Rare trials. Mean accuracy for OP trials including both 'YES' and 'NO' relatedness judgments was 57.3%; statistically, participants were performing better than chance, $t(34) = 4.317$, $p < .05$. Mean accuracy for Untrained Rare trials was 54.1 for both "YES" and "NO" relatedness judgments, this value was also significantly different than chance, $t(34) = 2.787$, $p < .05$. These results are unexpected since the words studied in training were rare words that participants were very unlikely to have seen before or even have a vague idea of their meaning. However, when we considered our significant interaction between Word Type and Relatedness, these results became not so surprising. Since our participants had a strong "NO" bias for these words, their accuracy for "NO" trials was higher (e.g. above chance) than what was predicted; these accuracies for the "NO" trials were driving the significant effects for OP and Untrained Rare conditions.

3.2. ERP Data

The ANOVAs for ERP data analyses were completed for three time windows, 100 to 300 ms, 300 to 500 ms, and 500 to 700 ms using data averaged for each experimental condition recorded at each of the 13 standard electrodes sites based on the 10-20 system (F3, Fz, F4, C3, Cz, C4, P3, Pz, P4, O1, O2, T7, and T8). Figure 2 shows a schematic of the electrode locations on the scalp.

Figure 2 Map of Electrode Locations on the Scalp



10-20 System	Electrode Number
F3	25
Fz	11
F4	124
C3	37
Cz	129
C4	105
P3	53
Pz	68
P4	87
T7	49
T8	109
O1	72
O2	77

These 200 ms time windows were selected based on a ± 100 range based on the average the latency for which the components of interest occur after stimulus presentation (e.g. ~ 400 ms for the N400, etc). The ANOVA factors corresponded to Hemisphere (left, midline, and right) and Lobe (frontal, central, parietal, temporal and occipital). Though, it should be noted since temporal and occipital electrode locations do not have a "midline", separate ANOVA's were completed for midline and lateral sites. The midline locations were tested using a Word Type (5; OM, OP, PM, Known, Untrained Rare) x Lobe (3; Frontal, Central, Parietal) with a between subjects variable of Skill (3; High, Middle, and Low) ANOVA. Lateral locations were tested using a Word Type (5) x Lobe (3) x Hemisphere (2; Left and Right) with a between subjects variable of Skill (3) ANOVA. Further, analyses were completed for both mean amplitude and latency effects. This resulted in four repeated measures ANOVAs at each time window; two

mean amplitude analyses, one for midline sites and another for lateral sites, and two for latency analyses, one for midline sites and the other for lateral sites. Mean amplitudes values for each time window were derived by averaging together the amplitude values (in microvolts) for each time point in the specified range of the time window. Latency values used for the analyses reflect the time (in milliseconds) to either most positive or negative peak in a given time window. Greenhouse-Geisser (*GG*) correction (Greenhouse and Geisser, 1959) was applied to all factors levels that violated sphericity. Waveform averages for all subjects and by comprehension skill are shown in Figures 3, 4, 5 and 6.

Figure 3 All Readers

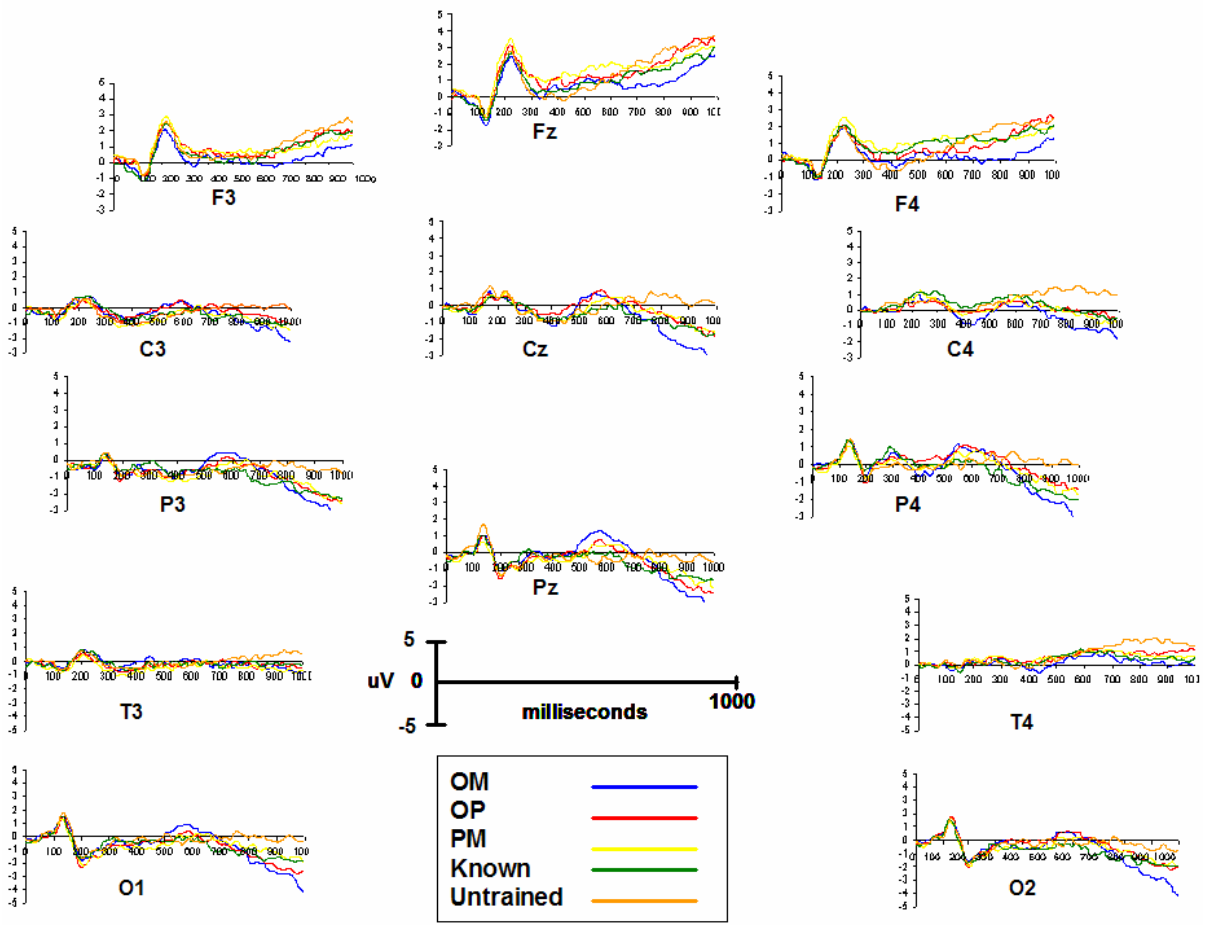


Figure 4 High-skilled Readers

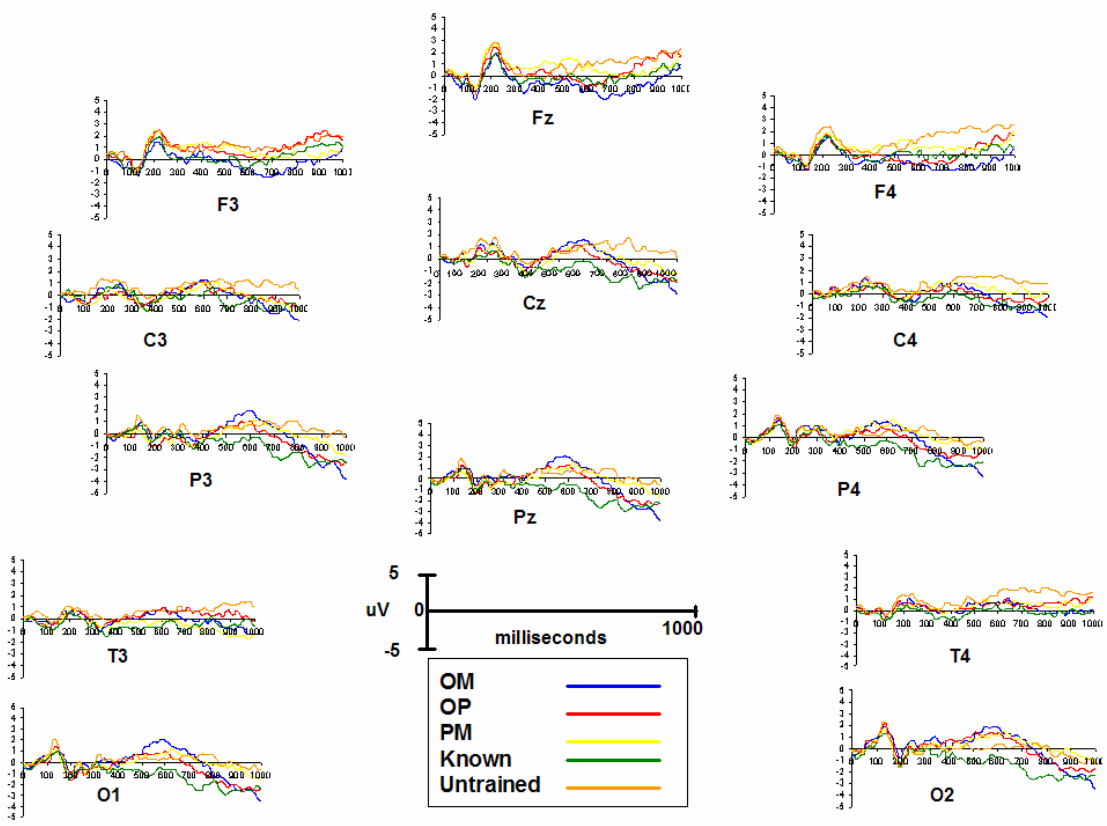


Figure 5 Middle-skilled Readers

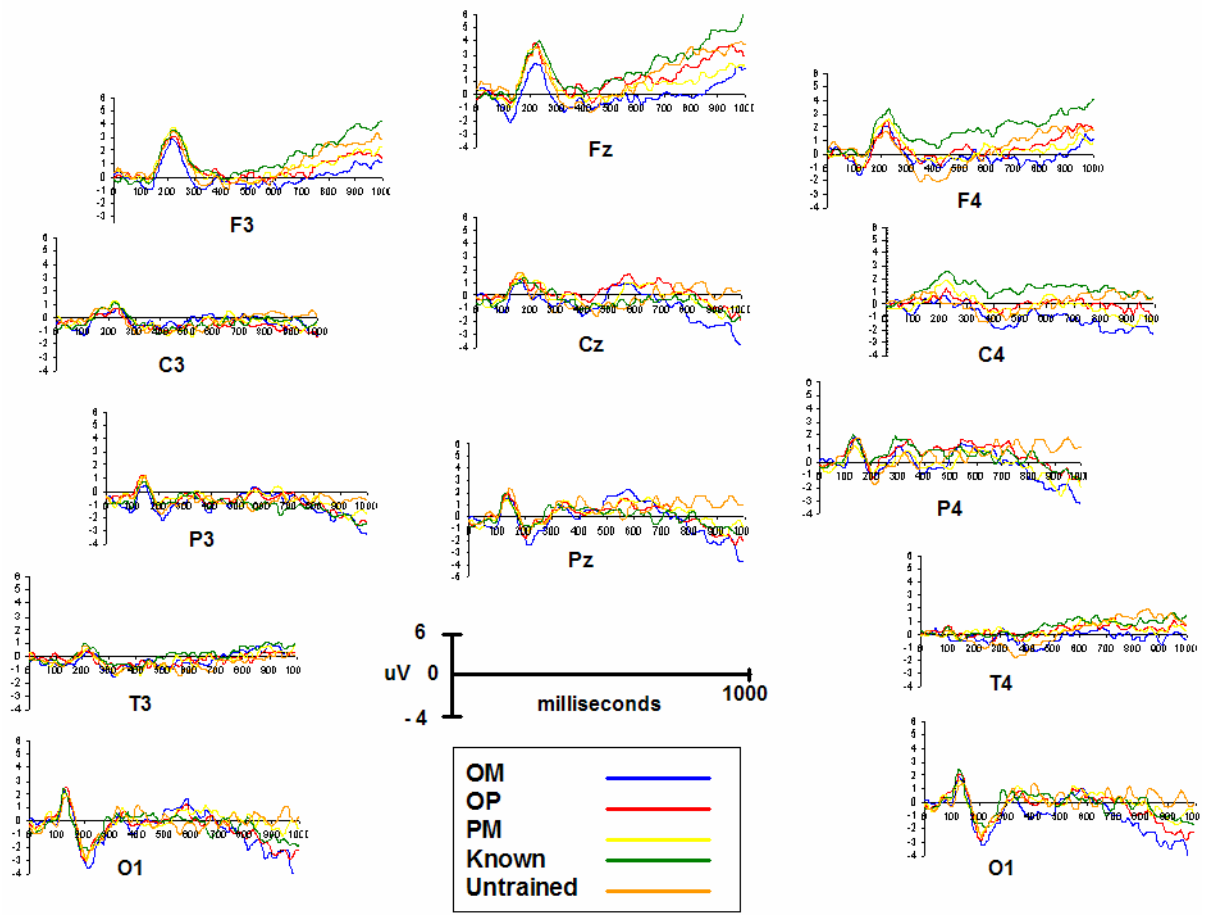
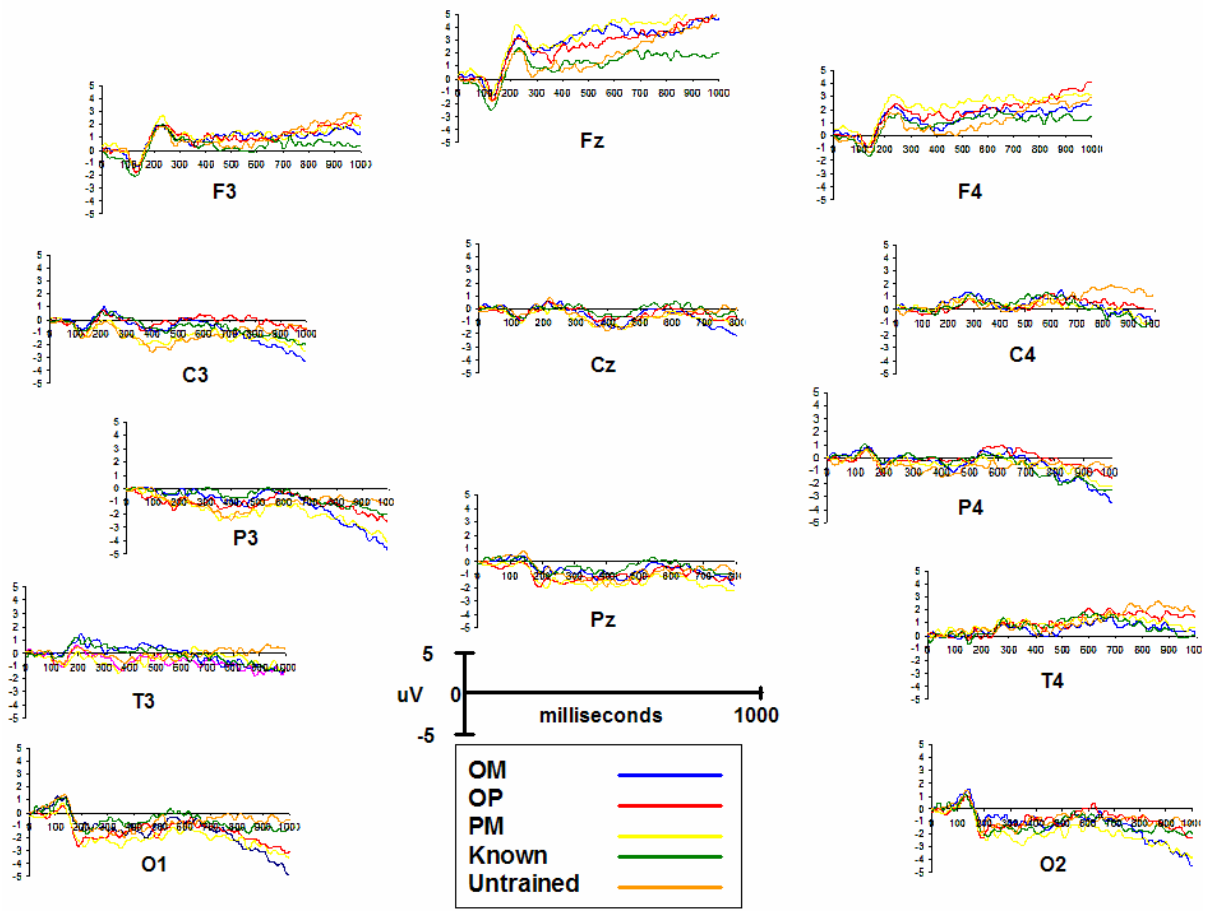


Figure 6 Less-skilled Readers



Our ERP results are reported for each time window by electrode site (midline or lateral) and type of analysis (i.e. amplitude or latency). All significant findings are reported. Many of the significant effects reported show main effects and interactions for Lobe and Hemisphere factors. While these results are interesting, scalp distributions of these different components are not of main interest for this current study. We report these findings because we want our audience to know the scalp distributions for our ERP findings, but no attempt was made to link these results to the current findings in the literature. The main focus will be to link findings associated with the training manipulation and comprehension skill to those already existing in the literature.

3.2.1. <u>100 to 300ms</u>

3.2.1.1. Mean Amplitude, Midline Sites

Midline ANOVA showed significant main effects for Lobe, F (2, 58) = 7.185, MSe = 223.88, $p < .01$, *GG* $\varepsilon = 0.560$, and no other significant main effects or interactions. This effect indicated frontal lobe positivity (M= 1.189), and negativity at central and parietal sites (M=-0.204 and M = -0.457). No other significant main effects or interactions were observed.

3.2.1.2. Mean Amplitude, Lateral Sites

Main effects were found for Lobe F (4, 116) = 8.25, MSe = 363.41, $p < .001$, GG ε = .359, and Hemisphere, F (1, 29) = 7.39, MSe = 62.71, $p <. 05$, GG $\varepsilon = 1.00$. Lobe x Hemisphere interaction was also significant, F (4, 116) = 6.50, MSe = 20.72, $p <.001$, *GG* $\varepsilon = 0.600$. Overall, greater mean amplitude positivity was located at right electrode sites; this differed for Frontal and Occipital lobes where no significant differences were found between right and left electrode sites. No other main effects or interactions of Word Type or comprehension Skill were found.

3.2.1.3. Latency, Midline Locations

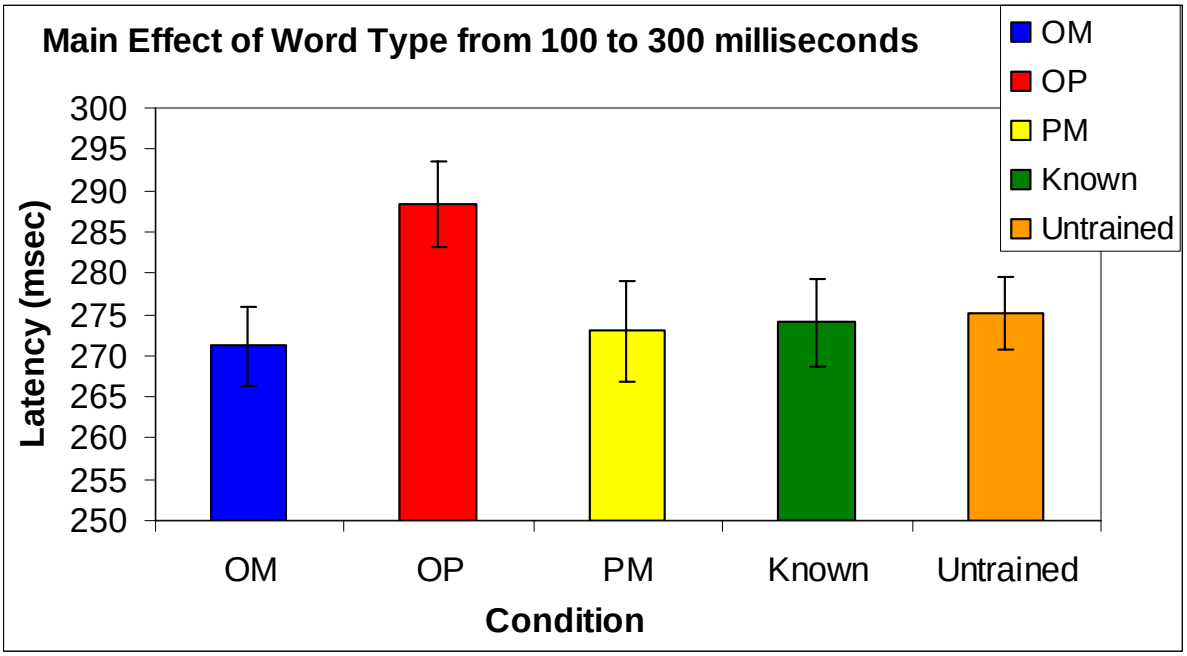
The midline analysis of amplitude at this time window indicated a significant Lobe effect; amplitudes were positive in frontal sites, but negative in central and parietal sites. Since we were interested in any ERP components that are occurring early (positive or negative), we had to account for latency to peak amplitude values that were positive at some electrode sites and negative at others. If we only account for latencies to positive peaks, we could have potentially bypassed interesting results at central and parietal sites. To avoid this problem, two ANOVAs were completed; one with latency values to positive peak amplitude, and another for negative peak amplitude.

Results for the analysis of latency to POSITIVE peak showed only a significant main effect of Lobe, F (2, 58) = 8.49, MSe = 102041.14, p < .001, *GG* ε = 0.820. No other main effects or interactions were found significant. This result corresponded with midline amplitude results; frontal and central sites showed shorter latencies (M = 252.75 ms and M= 257. 96 ms) than parietal site (M = 294.75 ms) to positive amplitude. This difference only reflects that positive amplitudes occur later in parietal sites than frontal and central sites because of differences in polarity for the initial components occurring after 100 ms. Findings for latency analysis to NEGATIVE peak also identified a Lobe main effect, F (2, 29) = 12.58, MSe = 96646.43, p < .001, *GG* ε = 0.890 where parietal site negativity occurred earlier (M = 283.87 ms) than central and frontal sites (M=325.74 ms and M= 327.19 ms). This result was expected given the previous ANOVA of latency to POSITIVE amplitude analysis showing that frontal and central sites show positive amplitude earlier than parietal sites. No other significant main effects or interactions were observed.

3.2.1.4. Latency, Lateral Locations

The analysis procedure used for latency to peak amplitude for midline locations was again repeated for lateral sites using latency values to positive peaks and to negative peaks in separate ANOVAs. POSITIVE peak analysis showed significant effects for Word Type, F (4, 26) = 3.38, MSe = 14950.66, p <.05, *GG* ε = .873. Figure 7 illustrates this result.

Figure 7 Effect for Word Type Latency to Positive Peak from 100 to 300 ms at lateral sites



OP trained words show later latencies to positive peak (M = 288.27 ms), regardless of electrode site, than all other experimental conditions which were not found to be significantly different than each other. Another main effect found to be significant was Lobe, F (4, 116) = 9.48, MSe = 190598.39, $p < .001$, *GG* $\varepsilon = 0.607$. This finding replicates the same results found in the midline analysis that parietal sites show later latencies to positive amplitude peaks. Finally, the main effect of Hemisphere F (1, 29) = 5.96, MSe = 4486.12, $p < .05$, *GG* $\varepsilon = 1.00$ and an interaction of Lobe x Hemisphere F (4, 116) = 3.34, MSe = 16217.38, $p < .05$, *GG* $\varepsilon = 0.769$ were also significant. Overall, positive peaks occurred later in right electrode sites, and these differences were more pronounced in temporal electrode sites.

The latency to NEGATIVE peak analysis revealed a main effect of Lobe, F (4, 116) = 12.35, MSe = 259606.45, $p < .001$, *GG* $\varepsilon = 0.618$, latency values to negative peaks were earlier occipital sites than other lobe locations. Also, the interaction of Word Type and Skill, F (8, 116) = 2.88, MSe = 21350.12, *GG* $\varepsilon = 0.763$ was significant. Low skill comprehenders show negative

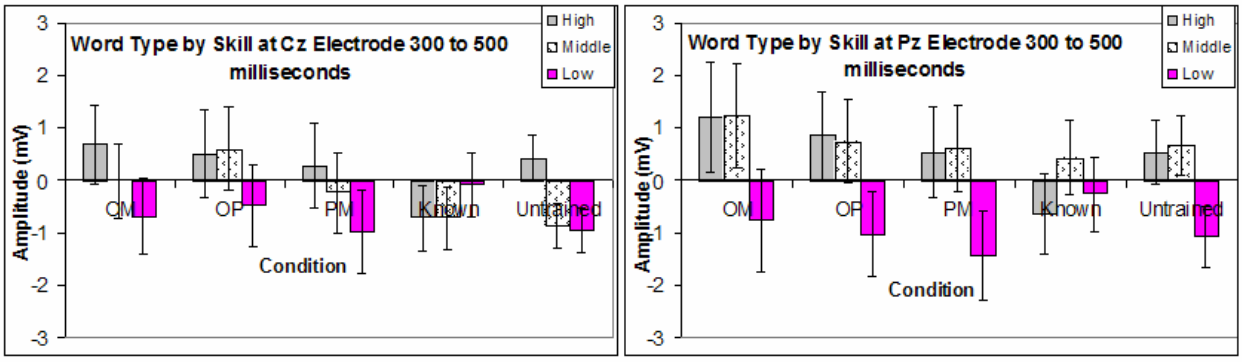
amplitude peaks for Untrained Rare (M = 327.32 ms) words occurring later (~ 30 ms) than high and middle skill comprehenders (M = 292.98 ms and M = 296.8 ms).

3.2.2. 300 to 500 milliseconds

3.2.2.1. Mean Amplitude, Midline Locations

Significant effects were observed for the interaction between Word Type x Lobe x Skill, F (19, 232) = 2.882, MSe = 9.92, p < .01, *GG* ε = 0.560. No main effects or other interactions were found significant. Figure 8 shows mean amplitude values for each of the experimental conditions across skill groups for central and parietal sites.

Figure 8 Word Type x Lobe x Skill Interaction for Mean Amplitude at Central and Parietal Midline Sites from 300 to 500 ms



In central site, skilled comprehenders show greater amplitude positivity for Untrained Rare words than middle and low comprehenders. This finding does not support our hypothesis that increased negativity would be observed for words that were not in training. At parietal site, low comprehenders show significantly greater negativity for OP, PM, and Untrained Rare words

3.2.2.2. Mean Amplitude, Lateral Sites

ANOVA revealed only one significant effect for the main factor of Hemisphere, F (1, 29) = 7.29, MSe = 72.56, p < .05, *GG* ε = 1.00. Mean values show greater negativity for left

electrode (M= -0.197) sites than the right sites (M = 0.229). No other main effects or interactions were found for Word Type, or comprehension Skill

3.2.2.3. Latency, Midline Sites

Latency values were derived by finding the time in milliseconds to the most negative peak from 300 to 500 ms since the component of interest, the N400 peaks approximately at around 400 ms. Analysis revealed a significant interactions of Word Type x Lobe, $F(8, 232) = 3.46$, $MSe = 12445.53$, $p < .01$, *GG* $\varepsilon = 0.664$, and a Word Type x Lobe x Skill, $F(16, 232) = 2.66$, $MSe = 9559.09$, $p < .01$, *GG* $\varepsilon = 0.664$. Frontal site indicated later latencies to negative peak than central and parietal sites. However, N400s that are associated with semantic processing and word level processing are distributed centro-parietally (Kutas & Hillyard, 1980, Nobre & McCarthy, 1994; Rüsseler et al., 2003). While the negativity observed at frontal sites well may be a N400 component, it is probably not associated with semantic processing or the old/new word effect, and thus the observed latency differences probably do not reflect differences in the experimental manipulation that are of interest. The Word Type x Lobe x Skill interaction indicates interesting differences in latencies between high and low skill comprehenders. In central site, low skill comprehenders show later latencies to OP words (M = 482.18 ms) than high skill comprehenders (M= 444.4 ms). No other significant interactions or main effects were found.

3.2.2.4. Latency, Lateral Locations

No main significant main effects were observed at lateral sites for this time window, However, two interactions were significant; Word Type x Lobe, $F(16, 464) = 2.38$, $MSe = 11742.27$, $p < .05$, *GG* $\varepsilon = 0.557$, and Lobe x Hemisphere, $F(4, 116) = 2.91$, $MSe = 12638.53$, p

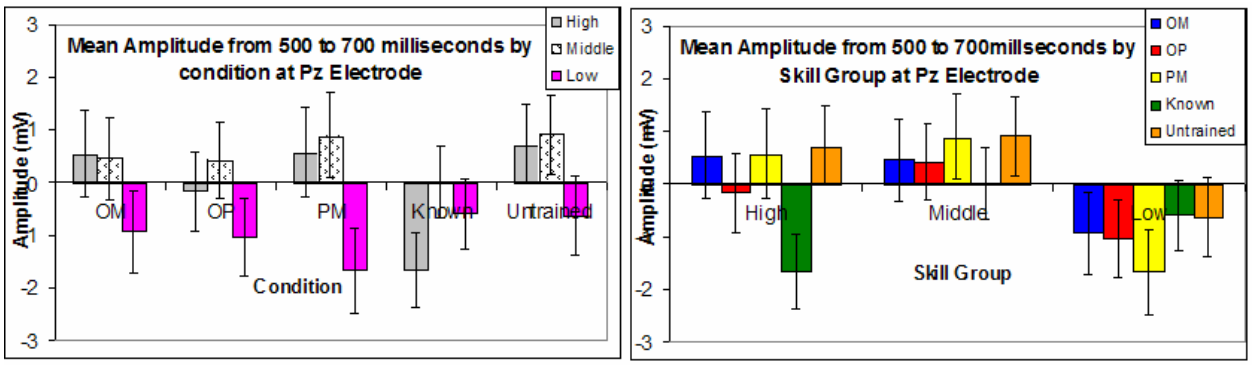
< .05, *GG* ε = 0.725. Significantly later latencies for negative peaks were observed at frontal sites for OM, OP, and PM words, but not at other electrode sites. The Lobe x Hemisphere interaction revealed slightly longer latencies for right electrode sites at Frontal and Temporal lobes.

3.2.3. 500 to 700ms

3.2.3.1. Mean Amplitude, Midline Sites

Significant main effects were observed for Lobe, F (2, 58) = 4.19, MSe = 237.34, p < .05, *GG* ε = 0.556. Mean amplitudes in this window were more positive in Frontal site (M = 1.45) than central and parietal locations (M= -0.102 and M = -0.141). The significant interaction between Word Type x Lobe x Skill, F (16, 232) = 2.99, MSe = 12.14, p < .01, *GG* ε = .575, indicated increased negativity on PM words for low skill comprehenders in comparison to high and middle comprehenders in parietal site. In addition at this same electrode, high comprehenders show an increased negativity only for known words that was significantly different than OM, OP, and PM words, but not for Untrained Rare words. These effects are illustrated in Figure 9.

Figure 9 Word Type x Lobe x Skill Interaction for Mean Amplitude at Central Midline Location from 500 to 700 ms by Condition and Skill group



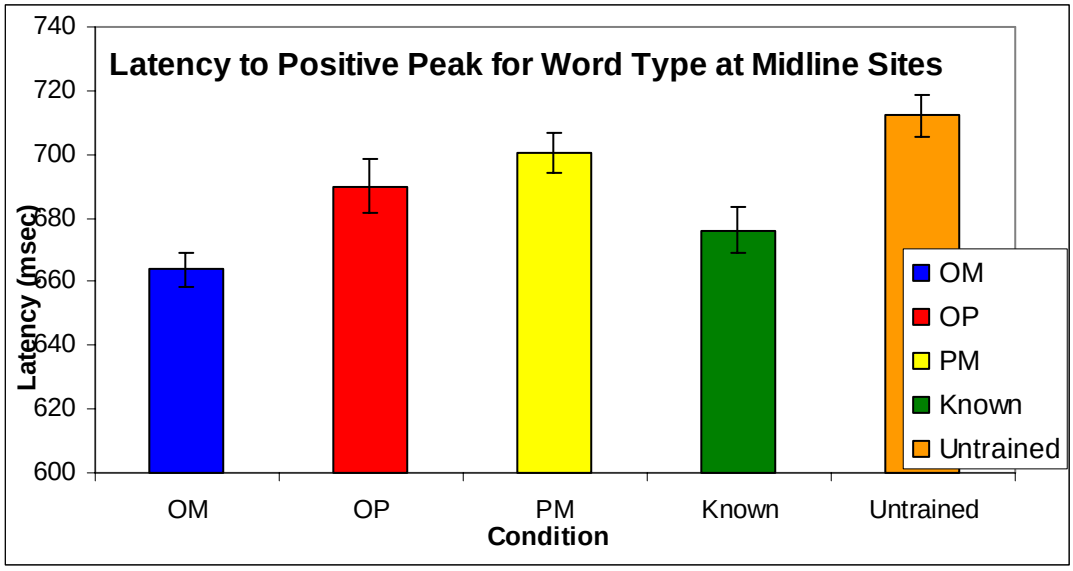
3.2.3.2. Mean Amplitude, Lateral Sites

Results show significant effects for Hemisphere, F (1, 29) = 9.41, MSe = 112.17, p < .01, GG ε = 1.00, and Lobe x Hemisphere interaction, F (4, 116) = 3.18, MSe = 18.99, p < .05, GG ε = .698. Findings indicated greater positivity from 500 to 700ms for right electrode sites, except for Frontal and Occipital electrodes which did not show significant differences between right and left locations.

3.2.3.3. Latency, Midline Sites

In this time window, latency values were derived from finding the time in milliseconds to most positive amplitude peak from 500 to 700 ms, since our latency of interest for the P600 effect is approximately 600 ms. Significant main effects were observed for Word Type, F (4, 26) = 11.99, MSe = 35265.73, p < .001, *GG* ε = 0.758, and Lobe, F (2, 28) = 6.14, MSe = 29658.73, p< .001, *GG* ε = 0.961 where Frontal lobe showed earlier latencies for P600 than central and parietal sites. The effect of Word Type is illustrated in Figure 10.

Figure 10 Effect of Word Type Latency to Positive Peak from 500 to 700 ms



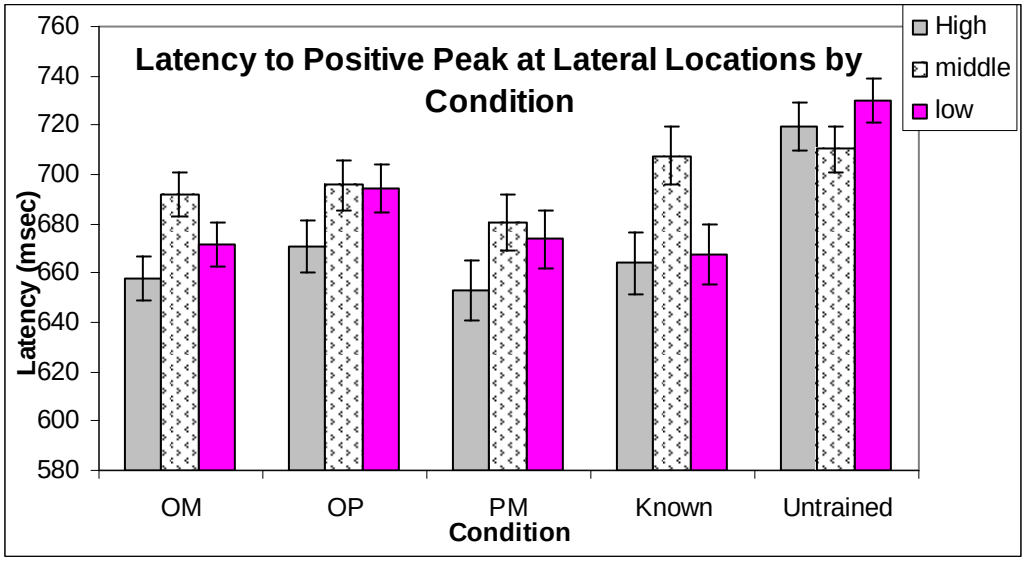
The latency of the P600 occurred significantly earlier for OM trials than for all other rare words (i.e. OP, PM and Untrained Rare). The interpretation of the differences in latency values between OM and Untrained Rare words should be interpreted with caution. Our initial hypothesis predicted that there would be increased positivity or a separation between the waveforms for words that appeared in training versus words that did not. While our amplitude analysis did not show this to be a significant Word Type result, looking at the waveforms from Figure 3 there is a trend toward this separation between old and new items. As a result, because there is reduced positivity for Untrained Rare and Known words at this time window, we would expect that positivity would occur slightly later after the waveform recovers from negative going waves. We do not believe that this current effect of Untrained Rare words reflects a later recovery from the negative going peaks at around 600 ms because we would expect to see Known words to show later latencies to positive peak too. However, there was no significant difference between the latency of OM and Known words. Thus, Untrained Words are showing slower episodic retrieval for all participants. Finally, the interaction between Word Type x Lobe, $F (8, 232) = 5.93$, MSe= 41819.71, $p <. 001$, *GG* $\varepsilon = 0.542$ indicated no differences in latencies between central and parietal sites for all conditions. At frontal site, latencies for OP, PM, and Known words occurred earlier than at central and parietal sites, however, this differed for OM and Untrained Rare words that which showed increased latencies of the same magnitude as in central and parietal sites.

3.2.3.4. Latency, Lateral Locations

Analysis at this time window for lateral sites showed a significant main effects of Word Type, $F (4, 26) = 22.98$, MSe = 129523.54, $p < .001$, GG $\varepsilon = 0.812$, and Lobe, $F (4, 116) =$

19.62, MSe = 239403.86, p <. 001, GG ε = 0.522. Latency to positive peaks were significantly later for Untrained Rare words, (M = 719.93 ms) than for all other experimental conditions (OM, M = 673.75 ms, OP, M = 687.02 ms, PM, M = 669.20 ms, and Known, M = 679.85 ms), and latency was significantly slower in Frontal locations than all other sites (e.g. Central, Parietal, Temporal, and Occipital). The between subjects factor of comprehension Skill was also significant, F (2, 29) = 3.99, MSe = 76264.98, p < .05. Latency for high (M = 673.13 ms) and low skill (M = 687.55 ms) comprehenders was significantly faster than middle skill comprehenders (M = 697.17 ms). Also, the interaction of Word Type x comprehension Skill was also found to be significant, F (8, 54) = 2.48, MSe = 17292.45, p < .05, *GG* ε = 0.812. Figure 11 illustrates this effect.

Figure 11 Word Type x Skill Interaction for Latency from 500 to 700 ms at all Lateral Locations



For OM and Known words, middle skill comprehenders showed later latencies to peak amplitudes than the high and low skill comprehenders. High skill comprehenders' latencies were earlier for OP words than middle and low skill comprehenders.

4. Discussion

The goal of this current study was to establish how incomplete word knowledge that is available to a participant about a word later affects meaning judgments in adults of varying comprehension skill. We manipulated the type of word knowledge participants learned about rare English words in three different training conditions: Orthography-Meaning, Orthography-Phonology, and Phonology-Meaning. Later, participants encountered these trained words and had to make meaning related judgments about them. Both behavioral and ERP data indicated evidence for new word learning, and these results suggested that how participants processed these words also differed with comprehension skill. We first turn to discuss our behavioral results, followed by a discussion on ERP evidence for each time window and the components of interest. The goal of this current study was to establish how incomplete word knowledge that is available to a participant about a word later affects meaning judgments in adults of varying comprehension skill. We manipulated the type of word knowledge participants learned about rare English words in three different training conditions: Orthography-Meaning, Orthography-Phonology, and Phonology-Meaning. Later, participants encountered these trained words and had to make meaning related judgments about them. Both behavioral and ERP data indicated evidence for new word learning, and these results suggested that how participants processed these words also differed with comprehension skill. We first turn to discuss our behavioral results, followed by a discussion on ERP evidence for each time window and the components of interest.

4.1. Behavioral Data

Reaction time data showed significant effects for Word Type, Relatedness, and a two-way interaction between Word Type and Relatedness. However, no significant skill differences were found. Participants were faster overall on orthography-meaning trained (OM) words, and

slowest for orthography-phonology (OP) and Untrained Rare words. Overall 'YES' trials were faster than 'NO' trials, and the interaction indicated that 'YES' trials were faster than 'NO' trials only for Known and OM trained words.

Accuracy results indicated significant effects of Word Type, Relatedness, and a Word Type by Relatedness interaction. Participants were most accurate on OM words and Known words. Further, they were less accurate overall on 'YES' trials than "No" trials. Specifically, for OM, participants were more accurate for 'YES' trials than 'NO' trials, but more accurate on 'NO' than 'YES' decisions for OP and Untrained Rare words. This pattern indicates a 'no' bias for words that were either unfamiliar or not trained for meaning.

Neither reaction time nor accuracy data indicated significant differences across comprehension skill on performance on the meaning- relatedness task. Our prediction based on previous literature was that high-skilled comprehenders should perform better then moderately or low -skilled comprehenders on this task because they are better at learning new words (Daneman, 1984). However, when we considered that all participants learned the trained words to a 100% criterion regardless of comprehension skill, this finding is understandable. Each participant during training had to retrieve either the correct pronunciation or meaning correctly twice in a row for each word. As a result, each participant had the same word knowledge about the trained words upon beginning the post-training task. Imposing a 100% criterion regardless of comprehension skill was enough to eliminate any significant differences for performance on the meaning-relatedness task that may have been associated with differences in comprehension skill.

4.2. ERP Data

4.2.1. 100 to 300 milliseconds

At this time window we observed significant differences in latency to POSITIVE peak for Word Type. Words trained in the OP condition indicated later latencies (~290 ms) to positive peak than all other experimental conditions (~ 272 ms) at lateral sites, but did not differ by lobe or hemisphere. This finding does not fit with current literature that reports very early components at about 132 ms for word frequency and regularity effects (Sereno et al., 1998), and that reports of slightly later components for graphic processing at about 250 ms (Liu & Perfetti, 2003) (this latency was reported for negative components that specifically were distributed in occipital areas). However, our result is a positive component whose latency to positive peak occurs later for words for which participants did not learn the meaning, and its distribution is not specific to occipital areas on the scalp. While we cannot support this finding based on other literature, we attempt to explain its significance within the context of our experimental manipulation. OP trained words are difficult for participants to process during the meaning relatedness task; this was reflected in RT and accuracy. Missing meaning information in a task that requires the retrieval of meaning may cause a delay in processing for a word that the participant knows they have learned, but do not have the proper information to be able to make the decision. However, we did not observe this effect of later latency for the Untrained Rare words for which participants also do not have meaning knowledge. So, a possible explanation is that the delay in latency for OP trained words is associated specifically with missing semantic information for a word that has been learned. Replications of this finding are needed before we can clarify more confidently the significance of this positive component and its associated latency.

At the same time window we observed an interaction of Word Type and comprehension skill for latency of NEGATIVE peaks at lateral sites. Low- skilled comprehenders show

negative peaks for Untrained Rare words 30 ms later than high and middle skill readers. Bentin et al. (1999) have reported two negative components at approximately 320 and 350 ms associated with phonological processing with specific distributions over temporal sites that differed in amplitude and latency depending on the presentation of phonologically legal versus illegal stimuli. The negative component we observed in this time window was not specific to any scalp location, and thus, cannot be interpreted along the results reported by Bentin et al. (1999). With no precedence in the literature for such a negative component with similar latency and distribution, interpreting the current finding to account for the latency differences on Untrained Rare words across skill groups is difficult. The grand average latency for POSITIVE peaks is earlier (M = 276.30 ms), than NEGATIVE peaks (M = 306.69 ms) which leads us to believe that these peaks are two separate components, only that they are positive going in frontal sites and negative in posterior sites as the Lobe effects indicated in the amplitude analysis. Thus, future replications of these results are needed to conclude whether these components are sensitive to the way in which stimuli are learned, in addition to form processing as noted by other studies in the literature.

4.2.2. 300 to 500 milliseconds

The mean amplitude analysis for midline sites revealed that, at Central electrode sites, high skilled comprehenders show greater amplitude positivity for Untrained Rare words than middle and low skill comprehenders. We predicted that, as an extension of the findings by Rüsseler et al. (2003), we would observe reduced N400 negativity for words that were presented during word training. Further, words that were presented for the first time in the experiment should show increased negativity as compared to 'old' words (i.e. trained words). According to this hypothesis, increased negativity should be observed for words that were not in trained (i.e.

Known and Untrained Rare words). Middle skilled and low skilled comprehenders show this effect, but high skilled comprehenders do not show increased N400 negativity for these words, only for Known words. This finding indicates that high- skilled readers may be more attentive to the characteristics of rare words, and may have formed a representation for 'word class' that contains the features of rare words. The Untrained Rare words were very similar in their features to rare words in training. As a result, when high skill comprehenders process these Untrained Rare words, they probably knew that these words were not dissimilar than the words that they have seen in training causing a reduction in N400 negativity. Also, at parietal sites we observed an increased negativity for PM and OP words for low skill comprehenders when compared to other skill groups. As noted earlier in the introduction, low- skill readers do not benefit from aural exposure of a word for later orthographic decoding (Perfetti & Hogaboam, 1978). Our ERP results gives evidence to support previous findings that low skill comprehenders were not successful in decoding the orthographic representation of a word from the phonological information, thus, when PM words are presented, they show more difficulty in recognizing that this word was presented in training. The increased negativity for OP words for less- skilled readers is more difficult to explain. Since they have seen the printed word before, and it is being presented in the same modality during the meaning task, all participants should not have difficulty in recognizing that OP words are 'old' words. It is possible that low skill comprehenders are showing something different; this increased negativity for OP words may be involved in sensitivity for missing semantic information rather than recognition processes.

At the same midline sites we also found comprehension skill differences for latency to negative peak of the N400. Low- skilled readers showed later latencies for OP words in comparison to high skilled comprehenders. This finding in conjunction with the amplitude

differences observed at this time window suggest that low skilled comprehenders differences are sensitive to missing meaning information for words that they learned in training. It is unclear whether these differences in amplitude and latency are due to recognition processes such as old versus new item recognition or task demands. Participants know that they will see words that were not trained for meaning, and that they will have to make meaning judgments on them. The increased and later N400 negativity in this case may reflect the increased difficulty for low skilled comprehenders to perform the task demands (i.e. making a meaning judgment) because of the missing meaning information. For high skilled comprehenders OP words are still difficult for making meaning judgments, but they can resolve this difficulty with their own word knowledge. For example, for a word like 'yttrium' the participant may not know that it is a silvery metallic element, but based on their own word knowledge, they may be able to figure out that the suffix

'-ium' probably has to do with an element on the periodic table. Having this word knowledge in the case of our task makes processing OP words during meaning judgment a little easier for high skilled comprehenders.

4.2.3. 500 to 700 milliseconds

At midline sites we observed significant interaction for amplitude of P600 for Word Type by comprehension skill. Specifically, at Parietal site, low- skilled readers showed increased negativity for PM trained words. Our initial hypothesis was that words that were trained should show increased positivity in comparison to untrained words. Low skilled comprehenders are showing increased negativity for PM words in comparison to high and middle skill comprehenders. This finding indicated that low- skilled readers were not able to decode the phonology of the PM trained words into an orthographic representation as well as the other

comprehenders from information given in training. Thus, it seems that for PM trained words low skill comprehenders are less successful at decoding orthography from phonological information; this finding supports other behavioral studies that have shown similar effects with aural exposure of words (Hogaboam & Perfetti, 1978). Also, we observed at this electrode site differences in P600 old/new effects for trained versus untrained words. Low skill and middle skill comprehenders do not show specific P600 effects (i.e. no separation between trained and untrained words). High skill comprehenders do show a P600 effect, however the separation in amplitude is between rare words (OM, OP, PM, and Untrained Rare) and Known words. As our ERP evidence indicated, high skilled comprehenders seem to form a conceptual representation for rare words. They are also aware that they will see rare words during the meaning task that they learned in training but did not see before (i.e. did they not see the spelling of the words). Thus, high skilled comprehenders may be directing their attention to all rare words, regardless of whether they were trained or not. This in turn has an effect on the episodic trace that we observe for these individuals that included all rare words separating at around 600ms from known words. Our findings here are not supported by previous results of the characteristics of the P600 'old/new' effect (Curran, 1999; Allan et al., 1998, Rugg, et al., 1998); however we show the same evidence as Rüsseler et al. (2003) that low skill comprehenders fail to show P600 'old/new' effects.

5. General Conclusion

The behavioral data from our study have shown that criterion learning eliminates individual differences of comprehension skill on task performance. This was indicated by RT and accuracy data showing no differences among the skill groups on task performance. However, criterion learning did not eliminate differences in ERP components across comprehension groups. Evidence from N400 and P600 effects indicate that available word knowledge about a word and

previous lexical knowledge a reader has about words in general makes a difference on how new words are learned. Recognition of PM words was difficult for low skilled comprehenders; they were not as good at decoding phonological information as high skill comprehenders. Further, high skilled comprehenders were sensitive to the characteristics of rare words; this was reflected in P600 effect for rare words versus known words. Finally, data from the early time window indicated some early positive and negative components with differing scalp distributions that may be sensitive to our word training paradigm rather than form processing; these findings need to be followed up with future experiments to determine their significance. The results from this study suggest that new word learning is affected both by comprehension skill and the available information about the word during the learning episode.

APPENDIX A

Experimental Stimuli

Trained Rare Word	Definition	Sentence	Probe (stimulus)
abeyant	temporarily inactive	The plan was abeyant until we could get further funding.	suspended
afreet	a powerful evil spirit or gigantic monstrous demon in Arabic mythology	To protect herself from the evil afreet, she wore a garlic necklace around her neck.	demon
agog	in eager desire; eager highly excited	She explored the deck of the ship, agog with excitement for her first trip.	excited
alate	having winglike extensions or parts; winged	The alate seeds of the maple floated through the forest on the wind.	winged
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.	cupboard
arcuate	having the form of a	The arcuate arteries are small curved branches of arteries	curved

	bow; curved	supplying the brain with fresh blood.	
assuasive	soothing; calming	His assuasive remarks really helped the family in their time of need.	soothing
badinage	playful teasing; banter	The playful badinage of her coworkers made her office a fun place to work.	teasing
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.	volley
bawdy	humorously coarse; risqué. Vulgar, lewd	The men sat around smoking and telling bawdy stories about their youths.	rude
beleaguer	to harass; annoy persistently	The other children beleaguered the boy because of his lisp.	bother
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.	alcoholic
bivouac	an encampment for the night usually without tents or covering	Our troops retreated for the night and went into the bivouac.	camp
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.	coax
cabochon	a highly polished, rounded stone	The sapphire was cut like a cabochon for the ring.	Gem

cerulean	azure; sky-blue	The cerulean skies were mesmerizing to Pittsburghers who see gray, cloudy skies most of the year.	blue
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.	bargainer
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.	forest
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.	mild
cygnet	a young swan	The young cygnet was swimming closely next to his swan mother.	swan
dandle	to move (a small child) up and down on the knees or in the arms in playful way; to 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.	bounce
diptych	an ancient writing tablet	Ancient Greeks used diptychs to practice writing.	tablet
ersatz	imitation, fake, artificial	She wrote a letter full or ersatz sympathy to the coworker she never liked, who had just been fired.	synthetic
estival	of, relating to, or appearing in summer	Jenny's family always liked to spend some time estival at the Hampton's.	summer
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	attendant

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.	car
folderol	foolishness, nonsense	Her silly folderol comments discredited her ability to serve as governor.	nonsense
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.	rummage
frisson	a shudder of excitement	As we descended from the pinnacle of the rollercoaster track, we experienced a short frisson of excitement.	shudder
garboil	confusion; uproar	To avoid garboil, the twins never wore the same clothes.	confusion
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”.	candles
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.	dusk
glossal	of or relating to the tongue	His glossal nerve had been severed, leaving him with no feeling in his tongue.	tongue
gravamen	the most important part of a complaint	The gravamen found at the crime scene was sure to convict him of the murder.	complaint
grimalkin	a cat, especially an old	The irritable grimalkin would not play with the	cats

	female cat; an old woman considered to be ill-tempered.	other cats because she was too old to run around the house.	
hebetude	mental dullness or sluggishness	Some say that too much television is leading us toward a nationwide hebetude	dullness
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 goverment officials.	seven
hinny	the hybrid offspring of a male horse and 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.	animal
hubris	overbearing pride or presumption	With dizzying hubris, Shelley elevated the purpose of the poet over that of priest and statesman.	pride
ibex	wild goat of mountain areas of Eurasia and N. Africa having large backward curving horns	The ibex wandered freely throughout the African mountains.	goat
illation	a conclusion, a deduction, or an inference	Faulty deductions or unimportant illations form a false image of things.	inference
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.	mosaic
jubilee	a season or an occasion of joyful celebration	Jessica was enjoying the celebrations of the annual spring jubilee with her family.	anniversary

junto	a small, usually secret, group joining for a common purpose	Chris joined the junto in hopes of meeting other Star Trek aficionados.	group
kilderkin	a cask; a small barrel; an old liquid measure containing 18 English beer gallons, or nearly 22 gallons	The tavern kept its beer supply in kilderkins behind the bar.	barrel
kittle	touchy; unpredictable	Because of her kittle personality, her friends never knew what to expect from her when they spent time together.	unpredictable
kyphosis	abnormal rearward curvature of the spine, resulting in protuberance of the upper back; hunchback	The hunchback of Notre Dame had severe kyphosis.	humpback
lacrimal	of or relating to tears	Tears are formed in the lacrimal gland, which is located under the upper eyelid.	crying
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.	criticize
legate	an ambassador or envoy	President Bush sent a legate to the Middle East to represent the United States at the peace talks.	representative
leister	a three-pronged spear used in fishing	Native Americans used leisters to catch their fish long ago.	spear
maculate	to spot, blemish, or pollute	She accidentally dropped her white scarf in the muddy puddle; the maculate was hard to get out.	stain

monish	to warn	His mother monished him of the consequences for driving without a seat belt.	warn
myxoid	containing mucous; mucoid	She had a myxoid cyst at the end of her finger.	Mucous
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.	turnip
natant	floating or swimming in water	She wanted to get some natant plants for the pond she dug in her yard.	floating
nebbish	a weak-willed, timid, or ineffectual person	He is a nebbish person who might be played effectively by Woody Allen.	timid
oblation	the act of offering something, such as worship or thanks, especially to a diety.	The priest reminded everyone to offer their oblation throughout the week, not just on Sundays.	worship
onus	a burden; an obligation; a difficult or disagreeable necessity	The onus was on the prosecution to prove the man had gotten sick because of his work environment.	burden
paranymph	the bridesmaid conducting the bride to the bridegroom	The bride has one chief paranymph that helps her out with the wedding plans; she is also known as the maid of honor.	bridesmaid
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.	wig

piaffe	a cadenced trot executed by the horse in one spot	To win the equestrian match, John trained his horse to do a fancy piaffe in front of the judges.	trot
pillory	a wooden framework on a post, with holes for the head and hands, in which offenders were formerly locked to be exposed to public scorn as punishment; to expose to ridicule and abuse	As a punishment for adultery, she was locked in a wooden pillory for a week at the center of town.	punishment
pintle	a hook or bolt on the rear of a towing vehicle for attaching a gun or trailer; the pin on which a gun carriage revolves; the pin on which a rudder turns; a pin or a bolt on which another part pivots; the one that holds a hinge together	The rusty pintles must be replaced soon before they snap, causing the door to fall off the hinges.	pin
pluvious	characterized by heavy rainfall; rainy	The pluvious weather lasted for days, causing a devastating flood throughout the small town.	rain
prescient	having foresight or knowledge of what will happen	His prescient that the Buccaneers would win the Superbowl was correct.	intuition
quahog	an edible clam of the Atlantic coast of N. America, having a hard rounded shell	The restaurant used only the freshest quahogs to make their famous chowder.	clam

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.	traitor
ramous	of or resembling branches	Some cancers grow in a ramous fashion, resembling tree limbs.	branching
refluent	flowing back, ebbing	The tide is refluent, so we'll soon be able to walk further down the beach.	returning
rivage	a coast, shore, or bank	She liked to wander along the green ravage in the spring, listening to the river.	seashore
roorback	a false or slanderous story used for political advantage	Politicians use roorbacks to defame the name of their opponents.	slander
salver	a tray for serving food or drinks	She put the drinks on the salver and headed out of the kitchen to serve them to her guests.	tray
schism	a separation or division into factions	The schism between East and West Germany ended when the Berlin Wall came down.	split
sibilant	of, characterized by, or producing a hissing sound like that of (s) or (sh)	The poet used a lot of sibilant consonants in his poem about snakes.	hiss
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.	sing
solleret	a flexible steel shoe forming part of a medieval suit of armor.	During battle, the knights kept their feet protected with steel sollerets.	armor

temblor	an earthquake	The temblor caused destruction throughout the city, and some could feel the tremor from miles outside of town.	earthquake
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.	coat
ultima	most remote; furthest; final; last; the last syllable of a word	They're traveling across Europe by train, and are planning on an ultima stop in Moscow.	final
unco	so unusual as to be surprising; uncanny; Extraordinary	He was a great traveling companion because of his unco sense of direction.	strange
uranic	of or relating to the heavens; celestial	It is an uranic principle that performing evil acts will bring punishment to the evil-doer.	heaven
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.	bear
urticant	causing itching or stinging	The sea anemone tentacles can be used to attack because of their urticant properties.	itch
venatic	of or relating to hunting	John always liked venatic sports such as deer and duck hunting.	hunt
venial	forgivable; excusable; pardonable	Eating meat on a Friday is a venial sin, but murder is a mortal sin.	forgiven

vesicate	to blister or become blistered	Her feet vesticated after wearing ill-fitting high-heeled shoes all day.	blister
vilipend	to treat something as if it has little value; to express a low opinion of	He thought I was vilipending his effort, but in actuality I appreciated his work very much.	belittle
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.	rod
vulpine	of, resembling, or characteristic of a fox; cunning; clever	The sly vulpine lurked behind the trees preparing to attack his prey.	fox
wheedle	to entice by soft words; to cajole; to flatter; to coax; to gain or get by with flattery or guile	The school was always trying to wheedle contributions from the parents by telling them how bright their children were.	persuade
wyvern	a two-legged dragon having wings and a barbed tail	The brave knight fought off the ferocious wyvern and saved the kingdom.	dragon
xanthous	yellow; having light brown or yellowish skin	The xanthous coloring of her skin suggested she contracted jaundice.	yellowish
xerosis	abnormal dryness, especially of the skin and eyes	She always had horrible xerosis in the winter, and bought practically every bottle of lotion in the store.	dry
xylograph	an engraving on wood	She bought some beautiful xylographs to hang on her office wall.	engrave
xyloid	resembling wood; having	Wormwood is neither worm-shaped or xyloid.	wooden

	the nature of wood		
yagi	a sharply directional antenna	John adjusted the yagi on his television because he wanted better reception of the football game.	antenna
yashmak	a veil worn by Muslim women to cover their face in public.	In some middle eastern countries, women who do not wear their yashmaks in public can be arrested by the police.	veil
yenta	a person, especially a woman, who is meddlesome meddlesome or gossipy	The yenta is famous for knowing the latest rumors in town.	gossip
younker	a young person (especially a young man or boy)	Jan has a three year-old younker and two older daughters.	child
yttrium	a silvery metallic element	They learned in Chemistry class that Yttrium Oxide has industrial uses for the manufacturing of television sets.	metal
zecchino	sequin; a spangle often sewn on cloth	Mary was wearing a beautiful dress with golden zecchinos that sparkled.	sequin
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 heads.	cap
zydeco	popular music of southern louisiana 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.	music

Known Words		Untrained Rare Words	
Stimulus	**Probe**	**Stimulus**	**Probe**
appendage	limb	balatron	buffoon
arbitrate	decide	buccula	chin
aspire	hope	burghbote	donation
avid	eager	caitiff	coward
bewilder	puzzle	chiliada	thousand
botany	plants	cullion	rascal
brochure	pamphlet	demiurge	creator
enamel	coating	dithyramb	hymn
goulash	stew	eroteme	symbol
hobble	limp	jactancy	brag
horrify	scare	jowter	salesman
infantile	immature	kevel	hammer
intellect	mind	limacine	slug
jettison	discard	lohock	antibiotic
kayak	boat	lorgnette	glasses
lacerate	slash	martext	preacher
mannequin	model	muzhik	peasant
mimic	imitate	novercal	stepmother
moccasin	slipper	oubliette	dungeon
molecule	particle	oxter	armpit
muggy	humid	poulaine	shoe
nauseous	queasy	oiviut	wool
novice	beginner	ructation	burp
obligate	commit	saulie	mourner
organic	natural	sororate	marriage
parcel	carton	speculate	sharpen
peril	danger	tomalley	lobster
prudence	caution	tomentose	hairy
quantity	number	tregetour	magician
reluctant	hesitant	uloid	scar
remedy	cure	ustulate	burnt

revoke	withdraw
sentiment	emotion
skittish	restless
slaughter	kill
uxorcide	murder
wibrissae	whiskers
yataghan	knife
zori	sandle

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