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The Influence of Word Form on the Acquisition of Meaning: An Adult Visual Word Learning Study

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Similarity to known words has been found to influence novel word learning (cf. Storkel, et al., 2006; Bartolotti & Marian, 2014). The current study examines the influence of the orthographic and phonological typicality of novel written words on the acquisition of meaning and subsequent naming behavior for those items. The orthographic and phonological characteristics of novel words were manipulated to create high and low wordlikeness pseudoword stimuli, and the effects of orthographic and phonological typicality or wordlikeness were investigated separately. Participants learned pseudoword-picture pairs across eight learning epochs using a paired associate paradigm (Sandak et al., 2004), and read aloud trained and untrained pseudowords post-training. High orthographic wordlikeness and high phonological wordlikeness were associated with better learning of the paired associates. This dissertation adds to the evidence that models of word learning for skilled readers need to consider the regularities of spoken and written forms of the language, and proposes a hybrid model of word learning based on models of reading acquisition.

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An Adult Visual Word Learning Study

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Introduction

Living languages are continuously changing, with words coming into and falling out of use on a regular basis. Adult skilled language users adapt to these changes, and successfully learn and use new words throughout their lifetimes. Young children learn new words through spoken interactions, while the initial contact with new or unfamiliar words for adults is frequently through print. My intent in this dissertation is to investigate how the process of learning novel words in adult skilled readers is influenced by the cumulative effect of past experiences with the written and spoken forms of our language. Specifically, I intend to address how our knowledge of the regularities of the written and spoken forms of English acquired in past language experiences influences how we learn the meanings of novel words, as well as to address the potentially separate contributions of orthography and phonology during written word learning.

Learning can be broadly defined as a change in behavior as a consequence of experience. Word learning, then, can be considered as a change in behavior on lexical tasks as a consequence of language experiences, including prior experiences as a speaker and reader of a language. Gupta and Tisdale (2009) identified some general categories of spoken word learning investigation, including developmental acquisition of word forms and semantic representations, adult learning of word forms (e.g. lists of nonsense syllables), and the learning of expressive and receptive links between word forms and semantic referents. Within this last category fall those studies that explored the variables that affect the learning process, including the characteristics of the learner, the characteristics of the learning tasks, and the characteristics of the items to be learned. Relevant to this dissertation are the studies that focus on the characteristics of the item to be learned and the influence of existing language knowledge on the learning of new words and their meanings.

The role of prior knowledge in word learning

Skilled adult language users bring extensive knowledge about the words of their language to the process of learning a new word. This word knowledge includes information about the lexical and sublexical regularities of the phonological and orthographic forms, the associations between those forms. The correspondence between form and meaning is largely arbitrary in English, and the correspondences of various meanings with written and spoken word forms become part of long-term lexical memory. Orthographic and phonological word forms can be perceived as more or less typical of a language. In English, words like DIG and BUTTER have a more typical orthographic structure than words like YACHT and GNOME. Typicality is not just a subjective impression that a word looks or sounds wordlike, but that kind of subjective rating has been used to assess typicality (Gathercole, Willis, Emslie, & Baddeley, 1991). The typicality of a word or pseudoword can be quantified by relating it to measured characteristics of the words of a language, such as neighborhood size or density, or sublexical characteristics, including bigram and biphone probability. Using these values has allowed experimenters to measure differences between words in different languages as well as create pseudowords with specific lexical and sublexical characteristics. Thus these quantified items have been employed in examinations of the influence of phonological and orthographic typicality on word processing and word learning within and between languages.

Phonological similarity to known words has been found to facilitate the learning of new words during spoken word learning tasks. Service and Craik (1993) examined the role of similarity between a native and to-be-learned language by asking native English-speaking participants to learn word pairs that were real English words paired with either Finnish words or phonotactically legal English pseudowords. Half of the Finnish words contained vowels for which there is no English equivalent. They found that their participants more accurately recalled the phonotactically legal English pseudowords than the Finnish words, and concluded that phonological similarity to the known language facilitates word learning. In a study with native Japanese speakers, Feldman and Healy (1998) had participants learn definitions for English words that were either familiar in terms of the phonemes or phoneme sequences, or unfamiliar, containing sounds and sequences that don't occur in Japanese. They tested participants on the written and spoken forms of the English words and found that participants remembered more of the definitions for the more phonotactically familiar words at post-test than for the words with unfamiliar phonotactics in both written and spoken test conditions. The evidence from the Service and Craik (1993) and Feldman and Healy (1998) studies supports the contention that words containing phonemes that were familiar to the learner were easier to learn. It is important to note that the harder-to-learn words contained phonemes to which the participants had no prior exposure expressively or receptively, and learning words with these unfamiliar sounds was contrasted with novel words containing sounds with which the participants had experience and consequently would be easier to discriminate and pronounce.

As shown above, learning new words based on constituents already known was accomplished more easily than learning new words composed of unfamiliar constituents. The influence of prior knowledge on phonological typicality is not limited to the known/unknown contrast; it has also been studied by contrasting more and less frequently occurring sound combinations within a language. Storkel (2001, 2003) explored the effect of phonological typicality on spoken word learning in preschool children, and found that participants more easily learned the meanings of spoken nonwords representing nouns (2001) and verbs (2003) with greater phonotactic probability. However, these findings have not consistently been replicated. Storkel and Lee (2011) investigated the influences of phonotactic probability and phonological neighborhood size on novel word learning with preschool children, and reported that the children demonstrated more accurate pairing of less phonotactically probable novel words with their trained object associates immediately following the learning trials as well as better retention one week later. They also examined the influence of phonological neighborhood density and found that it varied with time, reporting better accuracy on the referent identity task for items from sparse neighborhoods immediately following training, but better retention of referent identity for words from dense phonological neighborhoods one week later.

The studies from Storkel and colleagues provided somewhat inconsistent evidence that phonological typicality affects the process of learning meanings for novel word. Similarly, no consistent advantage has been identified for high phonological typicality in learning to produce a spoken word form. Storkel, Armbruster, and Hogan (2006) reported no effect of phonotactic probability on completely correct picture naming responses by adult participants who learned nonword-object pairs in a story-based task, but naming performance was reliably better for trained nonwords from high-density phonological neighborhoods. While participants were required to learn meanings for these novel words, no results were reported regarding the influence of phonotactic probability or neighborhood size on the acquisition of semantic associates.

Much as phonological typicality of a word has been shown to affect spoken word learning in some contexts, the orthographic typicality of a word may also influence the ease with which skilled readers learn written words. In an investigation the effects of orthographic and phonological similarity, Ellis and Beaton (1993) required participants who had no prior knowledge of German to learn English-German word pairs. The degree to which the German targets followed the spelling patterns of English was computed using English positional bigram frequencies in the calculations. Additionally, the phonotactic familiarity of the German words was calculated using mean biphone probabilities, based on the probabilities of the biphones in English. Words were included that contained phonemes found in German with which the participants had no prior exposure. The written translation pairs were displayed as the German word was spoken. Their analyses indicated that while both phonological and orthographic typicality was correlated with more accurate translations from English to German, phonology had a stronger effect.

Rather than contrast the learning of written words that contained novel phonemes with novel words comprised of familiar phonemes, de Groot and Keijzer (2000) created an artificial language that was phonologically legal in Dutch and easily pronounceable for their native Dutch-speaking participants. The use of an artificial language allowed the investigators to systematically vary the degree of similarity between the known language and the novel translations. During this written language experiment, participants learned translations from Dutch words to the pseudolanguage. The translation pairs were either pseudo-cognates (e.g. *broer-breur*) with the word to be learned orthographically and phonologically similar to it's known associate, or pronounceable pseudoword non-cognates (e.g. *bruid-maffel*), and were tested the day of learning and one week later. The experimenters tested the participants' expressive recall of the translation pairs by visually presenting the Dutch word and asking the participants to say the translation. Their receptive recall was tested by presenting the written made-up translation and requiring participants to say the corresponding Dutch word.

The results reflected faster learning and better retention with less forgetting of the pseudo-cognates as compared to non-cognate pseudowords for providing the Dutch word of the pair (receptive) and the translation of the Dutch word (productive). They concluded that it is easier to learn word-meaning associates for words that are more similar to known words, and that those associations are better retained in memory than harder to learn words. They suggested that in the case of foreign vocabulary learning, cognate status affords advantages both during learning and during recall, with cognates providing stronger cues for their translation. In a follow-up visual word learning study (de Groot, 2006), pseudoword stimuli were created to reflect phonotactic typicality based on letter positional frequencies rather than cognate status, which involves overlap of both form and meaning. Participants saw paired associates, and then at test were shown the newly learned words, and were required to say the Dutch translation. Recall scores the day of training and one week later were lower for translation pairs containing pseudowords less typical of Dutch, with better retention of more phonotactically typical pseudowords. As participants were not directed to use a particular learning strategy, it is likely that recoding of the novel word occurred during training, which would actively engage both the phonological and orthographic forms.

In an alphabetic orthography, phonology and orthography are not unrelated, consequently the phonological characteristics of a written word are an important consideration when studying the influence of orthotactic typicality on novel written word learning in languages that use alphabetic orthographies. To examine the relationships between orthography and phonology during visual word learning, statistical analyses have been used (Ellis and Beaton, 1993) or researchers have employed some manner of establishing a degree of similarity between the known and to-be-learned words (de Groot & Keijzer, 2000; de Groot, 2006). Collisson, Aicher, Arthur, and Rueckl (manuscript in preparation) utilized pseudowords containing legal phonological and orthographic sequences in English, creating high and low wordlikeness pseudowords based on orthographic and phonological lexical neighborhood size, orthotactics, and phonotactics. High orthographic probability tokens were characterized by high phonological probability, and low orthographic probability items were were also low probability in terms of their phonological features. The authors contrasted performance on these more or less probable word forms in different visual word learning contexts and on subsequent test tasks. All participants engaged in two training conditions. In one, they learned semantic (picture) associates for the pseudowords. In the other, participants were required to count graphemes that would have ascending components if written in lower case (e.g. D, T, H), which focused their attention on the visual characteristics of the orthography. Following the training blocks, the participants read trained and untrained pseudowords aloud. The results suggested that greater orthographic and phonological similarity to existing words facilitated learning in both the semantic and orthographic training conditions. High wordlikeness items were also read aloud more quickly than low wordlikeness items whether or not they had been trained. There was an advantage in naming for having learned a meaning for the pseudowords as high and low wordlikeness items from the semantic learning condition were read aloud reliably faster than untrained items. The authors interpreted this advantage as an indication that recoding from orthography to phonology likely occurred as part of the strategies the participants' used to learn the meanings for the novel words.

An advantage for high wordlikeness items (as measured by biphone probability, phonological neighborhood, sum of bigrams, and orthographic neighborhood) on a written word/picture association learning task with a related spelling task was reported by Bartolotti and

Marian (2014). Their participants learned to associate meanings with high and low wordlikeness items through a forced choice task in which they were to choose the correct picture to correspond to the target written word. At the end of each of the five blocks of this semantic associate training, the participants then saw a target picture and were asked to type in the associated pseudoword. Higher probability novel words were associated with better accuracy on the picture/word association receptive task, as well spelling the word when shown the picture. The Collisson et al. and Bartolotti and Marian (2014) studies provided evidence that it is easier to associate meanings with more typically structured visual word forms that correspond to more probable phonological forms, as measured by lexical and sublexical properties of the orthography and phonology. The influence of typicality was also seen on the production measures, with faster and more accurate naming post-learning (Collisson et al.) and more accurate spelling (Bartolotti and Marian, 2014) associated with higher probability word forms.

In summary, there is evidence that prior knowledge of the regularities of a speaker's language influences behavior during novel word learning, with similarity to words in a known language having been shown to facilitate the process of learning novel spoken and written words. Specifically, more phonologically typical words have been found to be easier to learn during spoken word learning, and more orthographically and phonologically typical words easier to learn during visual word learning tasks. Higher phonotactic probability and larger neighborhood size have been associated with better accuracy of referent learning (Storkel 2001, 2003; Storkel and Lee, 2011) and with better naming of learned referents (Storkel, et al., 2006).

In written word learning, more probable orthographic sequences have been associated with better learning (Ellis & Beaton, 1993; Collisson et al. in preparation; Bartolotti & Marian, 2014). However, given the tight connection between connection between orthography and phonology in alphabetic languages, it is not clear if this learning advantage for more probable word forms is due to the orthographic regularities or the associated phonological probabilities associated with those orthographic forms. Ellis and Beaton (1993) commented that both orthographic and phonological similarity influenced written word learning, but that phonology had a larger effect. This may be at least in part due to their use of phonological forms that were completely unfamiliar to their participants. The Collisson et al. and Bartolotti and Marian (2014) results suggest that high wordlikeness facilitates associating meaning with word forms, but as the orthographic and phonological characteristics were intentionally covaried in those studies, it is not possible to determine if their results were due to orthographic or phonological typicality.

Influence of the latent code

For skilled readers, there is evidence that the phonological and the orthographic codes associated with an instantiated word are automatically engaged such that lexical processing activates both the encountered form of the word as well as the "missing" or latent form. In the Collisson et al. and Bartolotti and Marian (2014) studies, the better learning of more probable written forms may be related to the written form itself, or with the associated (latent) phonological form that was activated when participants were shown the novel words. The automatic activation of orthography and phonology during language processing of known words has been found to be bidirectional, and studies have demonstrated phonological effects during reading as well as orthographic effects during spoken word processing.

Orthography has been found to be engaged during a variety of spoken word tasks. Participants were faster to make rhyme judgments about word pairs if the words in the pair were orthographically similar (*pie*-*tie*) than if the words in the pair were spelled differently (*rye*-*tie*), even if the word pairs were presented auditorily (Seidenberg and Tanenhaus, 1979). On a pseudoword detection task, the degree of orthographic overlap between prime and target was found to influence performance on spoken word lexical decision task (Chereau, Gaskell, & Dumay, 2006). The authors used a prime-target manipulation that varied the amount of orthographic overlap (*dream-gleam* compared to *scheme-gleam*) but maintained the same degree of phonological overlap, in combination with an unrelated condition (*stove-gleam*). The authors found faster performance on those items with greater orthographic overlap between prime and target. They concluded that orthography is automatically evoked during the course of spoken word processing in experienced readers.

The engagement of orthography during auditory lexical decision was also evident in a masked priming experiment. To rule out the possibility of conscious awareness of the prime-target relationship as a factor in the Chereau et. al results, Taft, Castles, Davis, Lazendic and Nguyen (2008) conducted a masked priming spoken word lexical decision experiment. They created pseudohomograph nonwords that were phonologically similar to the target and could be spelled in the same way as the target and nonwords that were phonologically similar but could not be spelled like the target. They found a clear facilitation in performance on the items that were primed by the pseudohomographs as compared to primes that were only phonologically related. At least half of the participants denied any awareness of a connection between prime and target, and those that did detect a relationship described it in terms of sounding similar to the target. The authors concluded that the facilitation seen was the result of automatic orthographic activation during the course of spoken word processing.

The correspondence between the orthographic and phonological forms can vary in English, with resultant differences in the ease with which the latent code can be activated. Consistent words are words or word bodies for which there is only one instantiated spelling for the associated phonological form or only one instantiated pronunciation for a written form. The use of consistent words has been an important tool in the investigation of phonological effects during written word tasks and orthographic effects during spoken word tasks. In auditory lexical decision, longer reaction times were associated with words for which the rime of the target word could be spelled in more than one way in studies conducted in Portuguese (Ventura, Morias, Pattamadilo, &Kolinsky, 2004) and in French (Perre, Pattamadilok, Montant, & Ziegler, 2009), suggesting support from the latent orthographic code facilitated auditory lexical decision performance. Analysis of the event related potential data from Perre et al. (2009) study identified larger ERP's to inconsistent words in an early time window (300 to 380ms) and in a later time window (410 to 550ms). Their source estimation data localized areas of the left hemisphere associated with phonological processing as the source of the orthographic consistency effect on their task, and they suggested that the effect comes from within the phonological system.

The interaction between orthography and phonology has also been demonstrated in studies that have shown an influence of the phonological form of a written word on visual word tasks. Larger phonological neighborhoods were associated with faster responses in visual lexical decision (Yates, Locker, & Simpson, 2004; Yates, 2005) and with faster naming and semantic categorization of written words (Yates, 2005).

Many studies have utilized homophones (*meet/meat*) and pseudohomophones (*brane/brain*) to explore the influence of phonology during written word processing. The employment of homophones and pseudohomophones rests in the logic that since the orthography varies from the target word, any influence of the homophone or pseudohomophone on participant behavior during an experiment must be due to the phonological form of that item, supporting the contention that phonology is engaged during written word processing. Van Orden (1987) compared homophone foils (ROWS/ROSE) to yoked spelling controls (ROBS/ROSE) in a category verification task, and found a higher rate of false positive responses for the homophone foils. Better performance was associated with the presence of pseudohomophone masks in a backward masking word identification experiment in Serbian (Lukatela & Turvey, 1990) and with very short stimulus onset asynchronies (SOA's) in semantic priming studies in English (Lukatela & Turvey, 1991; Lukatela, Lukatela, & Turvey, 1993; Lukatela & Turvey, 1994a; Lukatela & Turvey, 1994b). These results provide evidence that access of phonology during visual word processing is rapid and automatic. In an event-related potentials (ERP) investigation, Braun, Hutzler, Ziegler, Dambacher, and Jacobs (2009) identified a pseudohomophone effect early in processing visual words, and suggested that this early engagement of phonology could influence lexical access.

It is reasonable to assume that processing patterns such as mandatory engagement of phonology during reading would also be involved in the process of learning new words. As in the investigations of known word processing, the tighter coupling of phonology and orthography seen in consistent words has been leveraged in a number of studies investigating phonological effects on written word learning. Typically developing and reading disabled elementary school-aged readers learned pronunciations for novel printed words that were either assigned a pronunciation based on the most common pronunciation of a single letter or bigram unit, or an exception pronunciation that violated expectations (Bailey, Manis, Pederson & Seidenberg, 2008). Both groups demonstrated better learning of pronunciations for the nonwords with common pronunciations. Similar findings were reported by McKay, Davis, Savage, and Castles (2008). They had participants learn pronunciations for spelling-sound consistent and inconsistent written words in two conditions: a non-semantic condition in which participants saw and heard the novel word and repeated it, and a semantic condition in which definitions and picture representations were also provided. There was no effect of learning a semantic associate, but naming responses were faster and more accurate for novel words that were spelling-sound consistent. In a second experiment, a pre-reading stage was introduced in which the participants repeated the pronunciation of the novel word following presentation on a video prior to engaging in the learning tasks. Faster and more accurate reading aloud post-training was associated with spelling-sound consistent novel words, but the inconsistent novel words learned in the semantic condition were named faster and more accurately than those learned in the non-semantic condition. The word-meaning associates in both experiments were trained to criterion up to a maximum number of exposures, but no data were presented on whether or not there was a difference in learning performance for consistent and inconsistent items.

An advantage for spelling-sound consistency on a naming accuracy and auditory lexical decision was identified when targets were initially trained in a spoken word paradigm (Rastle, McCormick, Bayliss, and Davis, 2011). Picture-word associations were trained across three consecutive days using spelling-sound consistent and inconsistent (KIRM/CHIRM) pseudowords. Adult participants were initially trained on the spoken word to picture association, and spellings were introduced on the second day of training. No differences in naming latencies were noted between the spelling consistency conditions prior to orthographic training, but responses to spelling-sound consistent items were reliably faster after orthographic training on the day of training (Day 2) and the following day. Responses to spelling-sound consistent items in auditory lexical decision on Day 3 were also reliably faster than responses to spelling-sound inconsistent items. No differences between the conditions were reported for spelling the words or choosing the correct spelling in a force-choice task. The authors did not present the data regarding the learning of the picture-pseudoword associates, so it is unknown if sound-spelling consistency also had an effect of the ease of learning the meaning for a novel word.

A consistent relationship between orthography and phonology facilitated the acquisition of the spelling of newly learned words. Burt and Blackwell (2008) found that consistency between orthography and phonology facilitated oral spelling performance after participants learned meanings for pseudowords. Participants were shown printed pseudowords along with definitions and were asked to say the pseudoword aloud and learn the definition. Faster and more accurate performance on post-training oral spelling was associated with pseudowords with consistent rimes. No data were presented on the influence of orthographic consistency on the acquisition of meanings for the pseudowords.

Consistent relationships between orthography and phonology have been associated with better recognition memory following word learning. McKague, Davis, Pratt, and Johnston (2008) had participants learn meanings for pseudowords that either had a consistent phonology to orthography relationship or were inconsistent. The training occurred across three days, with some participants engaging only with the spoken form of the pseudoword, and others receiving all training through reading. Orthographic knowledge of the newly instantiated words was assessed through visual lexical decision on the last day of training with participants from both training conditions. Trained words were to be treated as real words (“yes” responses). There was no difference between performances on consistent and inconsistent words that had been instantiated through reading, but responses were faster for consistent items that had been orally trained. While the participants were initially instructed that they would be expected to complete a comprehension test after the final training, no comprehension results were reported. The authors contended that orthographic recoding takes place during spoken word learning, and thus the relationship between phonology and orthography can influence the process by which the orthographic knowledge of a spoken word is acquired.

Considerable evidence supports the claim that the process of recoding into the latent form of word takes place in both spoken and written word learning, and that accessing the latent word form code during encounters with the presented code (orthographic or phonological) can facilitate learning of new word forms. However, the focus has been primarily on the effects of recoding on learning the spoken or written forms of words, with little attention given to the potential relationship between ease of learning the word form and ease of associating that form with meaning. Evidence for the supportive role of recoding from the encountered code into the latent code during the learning of meaning for novel words comes from a study done by Nelson, Balass, and Perfetti (2005). They used rare words that their participants did not know, and had them engage in learning under three conditions: learning the meaning given the word's written form, learn the meaning given the word's spoken form, or learn the pronunciation of the a word given its written form. They found that orthographically-based learning of meaning was associated with faster learning (as measured by fewer trials to criterion) and more accurate subsequent recognition of the word forms in an old/new discrimination task as compared to word learning based on spoken word. The "Self-teaching Hypothesis" (Jorm & Share, 1983) posits phonological recoding helps with learning novel words by allowing the reader to access information about sound-letter correspondences and produce a phonological identity for the new word. This phonological information then permits the reader to associate the written word form with its meaning. Consistent with those proposals, Nelson et al. (2005) suggested that the process of decoding the word during learning added a phonological code, and that the activated phonological information then strengthened or stabilized the orthographic representation. The apparent absence of a strong benefit from generating the latent orthographic code in the spoken word learning condition in the Nelson et al. (2005) study could be related to the asymmetries in computing phonology from orthography as compared to the greater variability in generating orthographic forms for a phonological form, with greater stability and higher quality afforded by more systematic correspondences in computing phonology from orthography (Perfetti & Hart, 2002). Alternatively, the differences between the orthographic and phonological learning outcomes could be due to the readers' history with the language processing differences of the learning tasks: computing a phonological form when reading may be more practiced for many readers than computing an orthographic form when listening.

Accessing the latent code depends not only the characteristics of the words, but also on the characteristics of the learner and the learning conditions. No difference was found between learning a word's meaning through its spoken and written forms for either reading disabled (RD) or typical reader adult participants when the participants were required to learn meanings for novel words based on their use in spoken or written stories (Howland & Liederman, 2013). RD participants did have difficulty on the learning task when the modality was switched from written to spoken and the targets had inconsistent spellings. The authors interpreted this difficulty as being related to participants automatically generating the missing code in a manner that reflected the participant's knowledge of English spelling to sound mappings. In the case of the inconsistent words, the code generated by the participants was often regularized, and did not match the phonological code provided by the experimenters in the spoken word learning task. The authors posited that the RD participants did not update their existing representation when new information was provided, but rather treated the pseudowords as entirely new. The lack of benefit from learning by reading in Howland and Liederman (2013), as compare to Nelson et al. (2005), may be a function of their stimuli, as Nelson et al. employed a much larger number of words which were longer in length (letters and phonemes) than those used by Howland and Liederman. The training tasks were different as well. Nelson et al. employed a definition-based learning task in which the meanings were explicitly provided. Howland and Liederman's participants learned the meanings of novel words within the context of short stories. It is possible the engagement of the latent code played a different role during the definition memorization task as compared to deriving meaning from sentential contexts, or that phonological recoding was engaged to a greater degree when participants were expected to learn a larger number of words.

Nelson et al. (2007) suggested that implicit activation of the phonological code during reading was responsible for faster learning of word-meaning associates as compared to spoken word learning of the same items. Overtly providing the orthographic and phonological codes simultaneously during word learning has been investigated as a means to eliminate any differences based on the ability to access a latent code and stabilize the emerging representation for certain populations. Developing readers are still establishing and practicing the links between phonology and orthography, so they presumably lack the experience and automaticity of more skilled readers. Consequently, their ability to generate or access the latent code is likely to be less efficient than skilled readers. This does not mean, however, that they are not sensitive to regularities of the language. Ehri and Rosenthal (2007) found better recall of word definitions and pronunciations of new words if the spelling of the word was casually presented along with pronunciation for second grade readers during the learning trials and at post-test. This was also true for fifth grade readers, with more skilled fifth grade readers demonstrating greater benefit from the combined presentation of orthography and phonology during definition learning than lower reading level fifth grade readers. In a follow-up study that included learning contexts that were more typical of classroom experience, Rosenthal and Ehri (2011) found that requiring fifth grade readers to read an unfamiliar word out loud resulted in better learning of pronunciation-meaning associations as compared to reading silently and underlining the word if unknown. This effect was greater for poorer readers, but only when they were specifically instructed to use this strategy. Ehri and Rosenthal proposed that orthographic forms help the readers store the pronunciations in memory, facilitating faster learning of the pronunciations. In turn, it is then easier to associate pronunciations that are better instantiated in memory with meaning.

Ricketts, Bishop, and Nation (2009) reported similar effects of orthography on spoken word learning. In that study, 8-9 year-old children were taught spoken nonword/picture pairs. Orthography was also presented for half of the nonwords. As in the Ehri and Rosenthal (2007) study, the researchers did not draw the children's attention to the orthography. The presence of orthography resulted in faster nonword-picture matching following training, and better spelling of target patterns of nonwords with inconsistent vowel and consonant patterns. The authors raised the point that this and other similar findings could be due to the relationship between orthography and phonology, or due to orthography being directly involved in learning the semantic referent.

Providing the orthographic code along with the phonological code has been found to facilitate the learning performance of adult second language learners during their encounters with words that contained new (non-native) phonemes. Escudero, Hayes-Harb, and Mitterer (2008) studied adult Dutch learners of English and found that presenting orthography along with phonology while learning the meaning for a word resulted in faster learning of the meaning, as demonstrated by participants learning in the combined orthography-phonology condition reaching criterion more quickly than when learning in the phonology only condition. Their results provide evidence that the orthographic knowledge of a word facilitates the developing representation when knowledge of the phonological constituent is weak. However, this result has not been consistent. Overtly providing the spoken form together with the written form of novel words containing unfamiliar phonemes was found to be helpful only for native English-speaking participants who already were proficient in a second language, but hindered the performance of word learners with limited second language experience (Kaushanskya & Marian, 2009).

In summary, information from the encountered code and the latent code impacts learning of word forms and associating those forms with meaning. Word form learning was more efficient when there was a consistent relationship between orthography and phonology, but information about associating meaning with those forms was not presented. The simultaneous presentation of orthography and phonology, providing unambiguous information about the written and spoken identities of a word, has facilitated learning of word forms and meanings. These findings speak to the value of developing stronger connections between the orthographic and phonological forms during word form learning, either through recoding or concretely providing the correspondences. However, the associations between orthography and phonology are only part of the process of written word learning. The language user's prior knowledge of the typicality of the orthographic and phonological codes is also relevant, with some evidence that it was easier to associate meaning with more typical forms (Collisson et al.; Bartolotti & Marian, 2014). As those studies covaried phonology and orthography, it is not possible to determine if ease of associating a novel written word with meaning was driven by the orthographic forms of the new words or the likely activation of their latent phonological forms.

Reading theory and word learning

For skilled readers, the task of learning a new word ultimately involves acquiring knowledge of the orthography, phonology, and semantics of that word and binding those constituents together. Some current theories of word learning (c.f. Davis & Gaskell, 2009 and Gupta and Tisdale, 2009) focus on spoken word learning, with no explicit role for reading or the influences of orthography. The data presented so far suggest that failing to address the role of orthography does not consider the unavoidable interactions between orthography and phonology in skilled readers and is not in accord with real-world word learning situations. Models of reading acquisition consider the roles of both phonology and orthography as well as their connections to word meaning and may be useful in providing a coherent account for the visual word learning findings in skilled readers. The Lexical Quality Hypothesis (Perfetti, 2007; Perfetti & Hart, 2002) and the Triangle Model (Harm & Seidenberg (2004, 1997; Seidenberg & McClelland, 1989) were originally developed to explain the process by which individuals learn to read. Their focus on the knowledge of the orthographic, phonological, and semantic constituents of words and the interaction of those constituents during word processing makes these theories well suited to the task of developing and testing hypotheses about word learning. The architecture of the Triangle Model has layers in the model corresponding to orthography, phonology and semantics. Word knowledge in this model is instantiated as the amount of activation in each of those constituent units, and the weights of the connections between them, with greater activation and larger weights associated with more frequently encountered words. When a reader encounters a written word, activation spreads through the system, flowing to both the phonological and semantic units. Consistent with evidence for mandatory activation of phonology during visual word processing (c.f. Van Orden, 1987; Lukatela & Turvey, 1990;

Lukatela & Turvey, 1991; Lukatela, Lukatela, & Turvey, 1993; Lukatela & Turvey, 1994), the model is structured such that phonology is mandatorily activated when accessing meaning from the orthographic form through the mechanism of spreading activation, and the continued spread of activation from phonology to semantics varies with the strength of the connections between orthography and phonology and the stability of the phonological representation being activated.

In a manner consistent with the architecture and implementation of the Triangle Model, the Lexical Quality Hypothesis also considers the contributions of the constituent representations as related to stability and quality, and their impacts on word processing. The Lexical Quality Hypothesis has often been used to characterize the reader's skills in terms of their individual competencies in each of the domains of phonology, orthography, and semantics, with more skilled readers having better established or higher quality representations in each of those areas, along with stronger integration of the constituents. However, the idea of constituent quality can apply not just to the reader, but also to the words that are read. From this perspective, the quality of a word representation is dependent on the quality of the component knowledge of each of the constituent representation features, and the constituent binding which occurs as a consequence of one or more constituents becoming well specified in the context of another constituent (Perfetti, 2007). The ease with which word identity can be accessed through the phonological or orthographic form of the word is a function of stability of the representation, and more stable, higher quality words are accessed faster and with fewer errors.

For the purposes of providing an account for the influences of prior knowledge and the contributions of the constituent domains of a word during word learning, I propose combining some of the key features of the Triangle Model and the Lexical Quality Hypothesis in order to operationalize constituent characteristics and test predictions about the possible roles of phonology and orthography during visual word learning. In this hybrid model of word learning, the quality of a constituent becomes a measurable set of lexical and sublexical probabilities, and the language system is tuned to these probabilities based on prior language experiences. Performance during novel word learning is predicted to vary according the quality of the constituents, implying that new words do not arrive on a blank slate and are influenced by the corpus of already known words. This is potentially at odds with the Complementary Learning Systems account (Davis & Gaskell, 2009), which proposes that learned information is initially stored in sparse, independent codes. This proposal was based on studies that investigated the role of consolidation on the effects that newly learned words had on existing words in the lexicon, not on how the existing lexicon affects the early encounters with novel words.

In keeping with the assumption of the Triangle Model that activation flows in all directions during the processing of orthographic input, I propose that skilled readers mandatorily access orthographic and phonological information about the word form that they encounter, regardless of the input modality, such that both form constituents are part of the processing from the first encounter. This is consistent with existing findings regarding non-optional phonological involvement in orthographic processing (e.g.Van Orden, 1987; Lukatela & Turvey,1993) and orthographic involvement in phonological processing (Ventura, et al., 2004; Chereau, et al, 2007; Taft et al., 2008; Perre et al., 2009). I propose extending these findings from known word processing to novel word learning. In this way, associating meaning with a novel written word would be dependent on both the orthographic and phonological characteristics of the item's form. Consequently, the task of learning the meaning of a novel printed word becomes more than just making the association between orthography and semantics, as that connection would also be influenced by the mandatory engagement of phonology, strengthening the learning of the orthographic form and creating an additional association between the phonological form and its meaning.

This role of phonology in the task of learning the meaning of a printed word allows for a potential influence of varying phonological probability on the ease with which the novel word is learned. The results of prior studies (Nelson et al.,2005; Ehri & Rosenthal, 2007; Escudero, et al., 2008; Ricketts, Bishop, & Nation, 2009; Rosenthal & Ehri, 2011) are consistent with my proposal that the phonological code, whether accessed through the decoding process or explicitly provided, facilitates the process of associating novel written words with meaning in skilled readers (but see also Howland and Liederman (2013) and Kaushanskya and Marian (2009) for counter examples). As in the Nelson et al. (2005), study, it is likely that the participants in the Collisson et al. (in preparation) activated the latent phonological code during word learning, as a matter of mandatory activation during decoding or perhaps also overtly through subvocal rehearsal as they attempted to memorize the word-picture associations. The participants in the Bartolotti and Marian (2014) study were required to type the new words during the production phase of the learning task, increasing the engagement with the phonological forms of the novel words. As the high wordlikeness items in those two studies had more probable phonological forms, it is possible that those participants were afforded a higher quality latent code for high wordlikeness items, which would have led to better specification of the emerging lexical representations. Thus, the latent phonological form is likely to be at least in part responsible for the benefit of high wordlikeness on learning. From the perspective of the hybrid model, as the high wordlikeness forms in those studies were more in keeping with the lexical and sublexical patterns of English, it is possible to consider them as having higher quality and better specified forms than the low wordlikeness items, and potentially those higher quality forms were more consistently and accurately accessed as activation flowed from the input (letter strings) to phonology and semantics during the process of learning the associated meaning. The low wordlikeness forms were less stable, and the flow of activation from these less stable constituents on to semantics would have been “noisier”, with less consistency and accuracy in the contact.

The present study

While it may seem rather obvious to suggest that “two codes are better than one” when learning the meaning of novel words, word-learning experiments that have considered the interaction between orthography and phonology have explored the role of the associations between phonology and orthography by manipulating consistency, but have not addressed the potentially separable contributions of the phonological and orthographic codes of the nonwords employed. To test the predictions of the proposed hybrid model, three experiments were conducted employing a wordlikeness manipulation based on the orthographic and phonological qualities of the items to be learned.

Experiment 1 tested the prediction that prior knowledge of the regularities of the alphabetic orthography used in English influences the process of learning new words in experienced adult readers, with greater orthographic typicality predicted to be associated with better learning of written words. To do this, pseudoword stimuli were created that varied only in their orthographic characteristics, with phonological typicality kept consistent between the high and low orthographic probability lists. Experiment 2 examined the role of the latent phonological code in visual word learning, and used pseudoword stimuli that were categorized as high or low wordlikeness based on their phonological characteristics, but did not vary in terms of their orthographic characteristics. Experiment 3 utilized the pseudowords from Experiment 2 to investigate the possible stabilizing influence of simultaneous presentation of phonology and orthography when learning meanings for words that varied on their phonological typicality. Participants in Experiment 3 were assigned to one of two conditions: the Promoted condition in which they heard the pseudoword as it was shown on the screen, or the Impeded condition, during which participants heard unrelated nonsense words while the target pseudowords were presented on the computer screen. A picture-word paired associate task was employed in the learning phase of all three experiments. This task was chosen as it has been used effectively in other word learning experiments (Sandak, Mencl, Frost, et al., 2004; Collisson et al., manuscript in preparation).

To investigate the effects of orthographic and phonological wordlikeness on the stability of the emerging lexical representations, participants in all three experiments completed two post-training measures: a semantic identity task and a pseudoword speeded naming task. The forced choice semantic identity task was chosen to assess recognition of the word-picture association in a context slightly different from the training context. Naming was chosen as a post-training measure as it measures a different aspect of learning, specifically considering the computation of phonology from the orthographic form of the pseudoword. Additionally, Collisson et al. found it to be sensitive to effects of word typicality following learning. A forced alternative choice semantic identity task was chosen to assess recognition of the picture associations for the pseudowords as responses during the training task focused on the category of the picture associate, rather than the specific picture, and it is possible that participants would learn the category but not the semantic identity assigned to the pseudowords. A wordlikeness effect is anticipated, with faster and more accurate responses predicted for higher OD and PD wordlikeness items on the semantic identity and the naming tasks. The proposed model of word learning predicts that higher probability word forms would be more easily associated with meaning. Consequently, in both the orthographic and phonological wordlikeness conditions, responses to the high wordlikeness items during the paired associate learning task were expected to be faster and more accurate than responses to low wordlikeness items on the learning task, and in subsequent follow-up tasks. The presence of a wordlikeness effect in Experiment 2, in which the pseudowords were categorized based on their phonological characteristics, would provide evidence supporting the hypothesis that the latent code influences visual word learning behavior, and that higher probability phonological forms can facilitate the developing associations between orthographic word form and meaning. In Experiment 3, faster and more accurate performance was expected in the Promoted condition, as providing a clear model of the phonological code for the pseudowords was predicted to stabilize the emerging representation. In summary, these experiments were designed to assess the role of prior knowledge in word learning by specifically manipulating the orthographic and phonological typicality of novel written words and measuring performance on the acquisition of meaning and subsequent naming behavior for those items.

Experiment 1

Method

Participants. Participants were monolingual native speakers of American English with no hearing of vision difficulties, by report. Thirty-three undergraduates from the University of Connecticut participated for course credit.

Stimuli and Materials. Pseudowords were generated using the ARC Nonword Database (Rastle, Harrington & Coltheart, 2002). Biphone probability was calculated using the Vitevitch online Phonotactic Probability Calculator (Vitevitch & Luce, 2004). Stimuli were chosen to fit into high and low “wordlikeness” categories, based on their orthographic properties (see Table

1). These high and low wordlikeness orthographically different (OD) pseudowords varied on bigram frequency and orthographic neighborhood measures, but did not vary on biphone probability, number of phonologic neighbors, or number of phonemes. As the intent of these experiments was to investigate the influence of the phonological and orthographic characteristics and not the strength of the connections between orthography and phonology, consistency of the rimes was not manipulated, and there were an equal number of consistent rimes in the high wordlikeness and low wordlikeness pseudowords. All pseudoword stimuli were 5 letters in length and pronounceable as monosyllables. All items were normed prior to inclusion in the experiment by asking a separate group of undergraduate students to read the set of candidate pseudowords aloud. All participants in the norming study reported that they were monolingual native speakers of American English. They participated for course credit, and did not participate in the subsequent experiment in which these stimuli were utilized. Candidate items routinely produced as existing words during naming, or produced as a two-syllable utterance were excluded from consideration for the final set of stimuli. For the purposes of counterbalancing, the stimuli for the experiment were divided into two sublists, with 20 high wordlikeness items and 20 low wordlikeness items on each list. The lists were rotated through the trained/untrained conditions across subjects, and each pseudoword was encountered by a given subject in only one condition. Black and white line drawings of nouns, primarily drawings from Snodgrass and Vanderward (1980), were used as the picture associates during the training phase and as the targets in a follow-up semantic identity task. There were a total of 8 semantic categories with 5 meaning associates in each category. Each category had high and low wordlikeness items, and the two category sets was employed with both pseudoword lists between subjects. Throughout the experiment, Eprime (version 2.0 Psychology Software Tools, Inc., Pittsburgh, PA.)

controlled stimulus presentation. All text stimuli were displayed on a computer monitor using black 18 point Courier font on a white background.

Procedure. Participants were seated in a chair in front of a computer in a room used for running experiments. All tasks were completed within one experimental session. The full session lasted approximately one hour. Participants began the session with a training task in which they were to learn the meaning associates for a set of pseudowords. They then named all 40 trained pseudowords along with 40 additional untrained pseudowords. After completing the naming task, participants then completed a semantic identity task in which they had to choose the picture from a field of four that represented the learned meaning of the written pseudoword on the computer screen.

Training. The learning task was adapted from the semantic training task described in Sandak et al. (2004), in which participants learned a picture associate for pseudowords, and responded yes/no to category probes during the learning trials. Reaction time and accuracy data were recorded by Eprime2.0. A break was provided after four training blocks.

The training began with an exposure block in which each pseudoword-picture pairing was displayed for 2000 ms following a fixation cross which was displayed for 1000 milliseconds. The pseudowords were presented in capital letters. There was a 750 ms interstimulus interval. After viewing all 40 pseudoword/picture pairs, the participants were then shown a fixation cross for 1000 ms, followed by a pseudoword that was displayed for 1500 milliseconds. This was followed by a category prompt, such as "*animal?*" which remained on the screen for 5000 ms or until the participant responded. The participants' task was to respond "yes" or "no" by pressing a key on the computer keyboard. Accuracy feedback was provided, along with the pseudoword and associated picture. There were eight training cycles of this nature, with all 40 pseudowords presented within each cycle. Within each training cycle, half of the correct responses were “yes” responses, and half were “no” responses. Across the duration of the experiment, the correct response to the probe regarding a given pseudoword was “yes” 50% of the time.

Naming. In the speeded naming task, participants were instructed to don a head mounted microphone. The 40 trained stimuli, along with 40 untrained stimuli (20 high and 20 low) were presented on the computer screen in a pseudorandomized order. The stimuli were presented in capital letters and remained on the screen for 10000 ms or until the participant’s naming response was detected by the computer. Reaction time was recorded by Eprime2.0; accuracy was scored during the experimental session by the experimenter in attendance.

Semantic identity. A fixation cross was displayed for 750 ms, followed by a pseudoword displayed in the middle of the screen surrounded by an array of four pictures: the target, a semantically related distracter (same category), and two unrelated pictures. A number was displayed below each. This array remained on the screen for 10 seconds or until the participant responded by pressing on a number on the computer keyboard that corresponded with the picture that was associated with that pseudoword. The locations of target and distracters were counterbalanced. There was a 500 ms interstimulus interval. All 40 items from the semantic training block were presented in random order. Accuracy and reaction time were recorded by Eprime2.0.

Results

Responses on all tasks with reaction times of less than 250 ms were considered to be spurious, and were removed from subsequent analyses. Reaction time analyses included only correct responses. Naming responses that were not related to the task but that triggered the voice key (coughs, sniffs, etc.) were removed from subsequent analyses.

Training. Accuracies and reaction times for the yes/no category judgments were submitted to a 2x2x8 analysis of variance (ANOVA), with counterbalancing list entered as a between subjects factor, and orthographic wordlikeness (high and low) and training block (1 through 8) entered as within subjects factors. Means are displayed in Figures 2 and 3. There was no main effect of counterbalancing list. There was a main effect of wordlikeness in the training results, with reliably fewer errors ($F(1,31) = 6.521$, $p = .016$, $\eta_p^2 = .174$) on trials with high wordlikeness items than low. Reaction times on the category judgments for high wordlikeness trials were faster than those for low wordlikeness trials numerically, but this trend was not significant ($F(1,31) = 3.279$, $p = .080$).

As expected, there was a main effect of training block in both the accuracy ($F(7,217) = 37.271$, $p < .001$, $\eta_p^2 = .546$) and reaction time analyses ($F(7,217) = 21.543$, $p < .001$, $\eta_p^2 = .410$), with performance faster and more accurate at the end of training. There were no reliable interactions between training block and wordlikeness in either the accuracy or reaction time analyses.

Naming. Naming reaction times and accuracies for the trained and untrained pseudowords were submitted to a 2x2x2 ANOVA, with training list entered as a between subjects factor, and wordlikeness (high and low) and training status (trained and untrained) entered as within subjects factors. Means are reported in Table 2. The main effects of wordlikeness were reliable in both the accuracy and the reaction time analyses: high wordlikeness items were reliably named more accurately ($F(1,31) = 15.339$, $p < .001$, $\eta_p^2 = .331$), and more quickly ($F(1,31) = 28.79$, $p < .001$, $\eta_p^2 = .481$) than low wordlikeness items.

There was also a reliable effect of training, as naming responses were reliably more accurate (F(1,31) = 4.963, $p < .05$, $\eta_p^2 = .138$) and faster (F(1,31) = 28.729, $p < .001$, $\eta_p^2 = .481$) for trained pseudowords than for untrained items. There was no significant interaction between wordlikeness and training status. Planned comparisons revealed that the wordlikeness effects were not driven exclusively by the trained items, as naming responses for high wordlikeness untrained items were faster (t(32) = -6.307, $p < .001$) and more accurate (t(32) = 3.831, $p = .001$) than naming responses for untrained low wordlikeness items.

Semantic Identity. Reaction time and accuracy data from the semantic identity task were submitted to a 2x2 ANOVA with counterbalancing list entered as a between subjects factor, and wordlikeness entered as a within subjects factor. Means are reported in Table 3. There were no reliable main effects or interactions apparent in the analyses. Post-hoc analyses were conducted in which responses to the target and the within-category distractor were counted as correct. No reliable differences between responses to high and low word likeness items were evident in terms of either reaction time or accuracy.

Discussion

High OD wordlikeness items were associated with more accurate category judgments during learning, but counter to the predictions, there was no reliable difference between performances on high and low wordlikeness learning reaction time data, nor was there a difference in performance between high and low wordlikeness items on the semantic identity task. There was a wordlikeness effect in the naming data, but training did not change the pattern: in both the trained and untrained condition, high wordlikeness items were named more quickly and accurately than low wordlikeness items in the trained and untrained conditions. Examination of the means shows that untrained high wordlikeness items were named more quickly and more accurately than low untrained wordlikeness items. This effect of wordlikeness in the naming performance on untrained items reflects the skilled language system's response to new stimuli, and provides evidence that would confirm predictions that orthographic typicality can impact naming performance on initial contact with a novel word. Participants were not required to say the pseudoword out loud during the training blocks, so one possible explanation for the differences seen in reaction time and accuracy between trained and untrained items is that repeated contact with the phonological form during decoding raised its activation level and thus facilitated naming performance on trained items. Beyond the effects of decoding, learning strategy may have played a role. No instructions were provided to participants as to how to learn the paired associates, so they were free to devise their own strategies to learn the associations. Some participants were observed to say the words under their breath during the experiment, while others reported using a rhyming strategy or making other connections to help learn the semantic associates. Each of these strategies engages phonology, which could have contributed to the naming performance differences between the trained and untrained items.

The results of Experiment 1 provided evidence that the characteristics of the input code (orthography) influenced accuracy during paired associate learning, as well as the accuracy and response times during pseudoword naming. The hybrid model of word learning predicts that visual word learning and subsequent naming performance would also be influenced by the latent code, with faster and more accurate performances during visual word learning associated with more probable phonological forms. This hypothesis was examined in Experiment 2 using phonologically different (PD) pseudowords. These contrasted with those used in Experiment 1 by varying on phonological characteristics rather than on orthographic characteristics.

Experiment 2

Experiment 2 was designed to test the hypothesis that the latent phonological code influences visual word learning, with better learning predicted for pseudowords with more probably phonological forms, even when they do not differ in terms of their orthographic characteristics. Specifically, faster and more accurate performance was predicted for items with high phonological wordlikeness during the category judgment learning task and the post-learning naming and semantic identity tasks. The experiment was set up to mirror Experiment 1, using the same methodology and picture stimuli sets.

Method

Participants. Participant requirements were as described in Experiment 1. Thirty-seven undergraduates from the University of Connecticut participated for course credit. One reported vision difficulties (nystagmus) and those data were removed from the analysis. No hearing difficulties were reported.

Stimuli and Materials. Pseudowords were generated using the ARC Nonword Database (Rastle et al., 2002). Stimuli were chosen to fit into high and low wordlikeness categories, based on their phonological properties (see Table 4). These high and low wordlikeness phonologically different (PD) pseudowords varied on biphone probability and number of phonologic neighbors, but did not vary on orthographic characteristics, specifically bigram frequency, orthographic neighborhood measures, or number of letters. The orthographic characteristics were limited to a range intermediate between the high and low wordlikeness characteristics manipulated in Experiment 1. Orthographic consistency was not manipulated, and there were an equal number of consistent high wordlikeness and low wordlikeness pseudowords. The high and low PD pseudoword lists did not vary on number of phonemes. All pseudoword stimuli were 5 letters in length and pronounceable as monosyllables. As in Experiment 1, the pronunciation of candidate items was assessed prior to inclusion in the experiment by asking a separate group of undergraduate students to read the set of candidate pseudowords aloud. All participants in this pronunciation study reported that they were monolingual native speakers of American English. They participated for course credit, and did not participate in any other part of this project. Candidate items routinely produced as existing words during naming, or produced as a two-syllable utterance were excluded from the final stimulus set. The stimuli for the experiment were divided into two sublists, with 20 high wordlikeness items and 20 low wordlikeness items on each list for the purposes of counterbalancing. The lists were rotated through the trained/untrained conditions across subjects, and each pseudoword was encountered by a given subject in only one condition. This experiment employed the same picture stimuli and presentation software as Experiment1.

Procedure. The procedure was identical Experiment 1.

Results

The criteria for inclusion into the analyses and the treatment of the data were as described in Experiment 1. The analyses of the Experiment 2 data were completed using the data from 36 participants.

Training. Training accuracies and reaction times were submitted to a 2x2x8 ANOVA, with counterbalancing list entered as a between subjects factor, and wordlikeness (high and low) and training block (1 through 8) entered as within subjects factors. During the training portion of Experiment 2, participants responded to high PD wordlikeness items reliably faster ($F(1,34) = 4.568$, $p < .05$, $\eta_p^2 = .118$) and more accurately ($F(1,34) = 6.272$, $p = .017$, $\eta_p^2 = .156$) than to low wordlikeness items (see Figures 4 and 5). As in Experiment 1, there was a main effect of training block in both the accuracy and reaction time analyses, with performance becoming faster

($F(7,238) = 20.094$, $p < .001$, $\eta_p^2 = .371$) and more accurate ($F(7,238) = 41.843$, $p < .001$, $\eta_p^2 = .552$) as training progressed. Analysis of the accuracy data revealed a significant interaction between wordlikeness and training block ($F(7,238) = 2.532$, $p = .016$, $\eta_p^2 = .069$): there was no reliable difference in the accuracy of responses to high and low wordlikeness trials in training block one ($t(35) = -.470$, $p = .642$), but responses were more accurate for high wordlikeness items in block seven ($t(35) = 3.935$, $p < .001$) and marginally so in block eight (($t(35) = 1.983$, $p = .055$) of training. The reaction time analysis did not reveal a significant interaction between wordlikeness and training block ($F(7,238) = 1.518$, $p = .162$).

Naming. Naming reaction times and accuracies were submitted to a 2x2x2 ANOVA; training list was entered as a between subjects factor, and phonological wordlikeness (high and low) and training status (trained and untrained) were entered as within subjects factors. Means are reported in Table 5. There was a main effect of wordlikeness in the reaction time analysis ($F(1,34) = 8.493$, $p = .006$, $\eta_p^2 = .200$); however faster naming times were associated with low wordlikeness items. There was no significant effect of wordlikeness in the naming accuracy analysis ($p = .836$). The main effect of training status was reliable in the reaction time analysis, but not in the accuracy analysis: trained items were reliably named more quickly than untrained items ($F(1,34) = 43.508$, $p < .001$, $\eta_p^2 = .561$), but not more accurately ($p = .103$) than untrained items. There were no reliable interactions in either the reaction time or error analysis.

Semantic Identity. The semantic identity accuracy data were submitted to a 2x2 ANOVA with counterbalancing list entered as a between subjects factor, and phonological wordlikeness (high and low) entered as a within subjects factor. Means are reported in Table 6. There was no reliable difference between responses to high and low wordlikeness items in the accuracy analysis ($p = .420$), but reaction times were marginally faster for high wordlikeness items than low ((*F*(1,34) = 83.974, *p* = .054). Reaction times and accuracy were not reliably different for high and low word likeness items in post hoc analyses in which responses to the target and the within-category distractor were counted as correct.

Discussion

The results of Experiment 2 provide some support for the hypothesis that the phonological form of a word influences performance during visual word learning. As expected, the accuracy of participants' responses to high and low wordlikeness items was at chance at the beginning of training, but participants were reliably more accurate on the high wordlikeness trials at the end of the training session, suggesting that it was easier to learn the meaning of a novel word if the phonological characteristics of that new word were more like existing words in the long term memory. There was, however, no strong evidence of advantage for high PD wordlikeness items on the tasks following training. There was no difference in naming accuracy between high and low wordlikeness items, and latencies were actually faster for low wordlikeness items. There was a marginal trend for performances on the semantic identity task to be faster for high wordlikeness items. The lack of a wordlikeness effect when reading the high and low phonologically typical (PD) words aloud suggest that the phonological form was not driving the differences seen in the Collisson et al. study, in which high wordlikeness words (based on orthographic and phonological characteristics) were named faster and more accurately than low wordlikeness words. As there was a wordlikeness effect in the naming data in Experiment 1 in which the stimuli varied only on the orthographic typicality, the naming performances in the Collisson et al. study were likely due to the orthographic characteristics of the pseudowords.

Reviewing the results of Experiment 1 and 2 together, it appears that both the orthographic (input) and the phonological (latent) forms of a visual word exert influence during the early stages of visual word learning. As the stimuli were all printed pseudowords with no auditory information explicitly provided, all access to the phonological form of the items occurred as a function of the participants' reading process. Faster and more accurate responses for the phonologically more probable stimuli during training provides evidence that novel orthographic word learning involves more than just making connections between orthography and semantics, and that the "missing" phonological code is accessed and its regularities influence the word learning process. The finding that the orthographic and phonological characteristics of a word influences word learning is consistent with the predictions of the proposed hybrid model: the stability of the novel word form representation was influenced by the both the word's orthography and its phonology, and the characteristics of the form influenced the process of learning meanings for the word. If, as Nelson et al. (2005) and Ehri and Rosenthal (2007) suggested, accessing or providing the "missing code" affects the quality of the developing word form representation and thus the ease of learning of the meaning of the word, then manipulating the extent to which the "missing code" is computed should influence word learning. This would imply that if access to the phonological code were to be impeded during word learning and the phonological information made unavailable, then there should be no effect of the phonological regularities during novel word learning. Specifically, if spreading activation from orthography to phonology is relevant during learning word meaning, then inhibiting access to phonology should eliminate the wordlikeness effect seen in Experiment 2, as learning would be based solely on the orthographic form of the word, and the orthographic characteristics in the PD stimuli did not vary between high and low wordlikeness. On the other hand, enhancing access to phonology by presenting the phonological form of a pseudoword in combination with the orthographic codes should improve the quality of the orthographic and phonological constituents, which should result in faster and more accurate performance during learning, as was seen in the Ehri and Rosenthal (2007) and Escudero et al. (2008) findings.

Experiment 3

Experiment 3 tested those predictions by manipulating the access to phonology from orthography during visual word learning events in order to determine if the wordlikeness effects on learning semantic associates are influenced by the engagement of phonology during the processing of the orthographic form. Two phonological access task conditions were created: a Promoted condition in which a visually presented pseudoword was presented simultaneously with its phonological form; and an auditory-unrelated condition (Impeded) in which a conflicting pseudoword was presented auditorily to interfere with accessing the associated phonological form of the pseudoword that was visible. In order to evaluate the influence of disrupting access to the phonological code, the phonologically different (PD) stimuli from Experiment 2 were employed in this experiment. Based on the results of the Experiment 2, interfering with access to the phonological code should eliminate the differences between the high and low wordlikeness items in the Impeded condition.

Method

Participants. Fifty-four University of Connecticut undergraduates (28 in the Promoted condition; 26 in the Impeded condition) participated for course credit. All reported that they were monolingual native speakers of American English, and did not have hearing or vision problems. None had participated in the previous experiments.

Stimuli and Materials. The phonologically different (PD) pseudoword stimuli from Experiment 2 were used. Audio recordings of the pseudowords were made in a sound proof room at Haskins Laboratories by an adult female native speaker of American English. Recordings were also made of a separate list of pseudowords that were employed during the Impeded Condition. Multiple pseudowords that did not correspond to the orthography, phonology, or syllable structure of the target items were used, consistent with the findings that the effect of presenting irrelevant speech during an orthographic memory task is greater when multiple tokens are used (Larsen & Baddeley, 2003). Those stimuli were five to six syllables in length. Three tokens of each conflicting pseudoword were used, and the conflicting pseudowords were not consistently paired with any of the orthographic forms to be learned. Three tokens of each pseudoword (PD stimuli and stimuli for presentation during Impeded trials) were used during the experiment.

Procedure. The learning task was as described in Experiment 1, with the following phonological access conditions. The phonological access manipulation was conducted between subjects, with some subjects hearing the pseudoword to be learned through headphones during the learning trials (Promoted condition), others hearing conflicting auditory stimuli (Impeded condition). The condition-specific auditory stimuli were provided every time the pseudoword appeared on the screen. In the Promoted condition, each pseudoword was accompanied by one of three recorded exemplars of that token. The presentation of the recordings for each pseudoword was pseudorandomized and was not associated with the required response for any particular trial (yes or no). In the Impeded condition, participants heard spoken pseudowords that did not occur in any other portion of the experiment. The onset of each recording was timed to occur with the onset of the visual presentation of the pseudoword.

As described previously in Experiments 1 and 2, all participants completed naming and semantic identity tasks following training. The Promoted and Impeded conditions were run concurrently.

Results

As in the previous two experiments, all responses with reaction times of less than 250 ms were considered to be spurious, and were removed from all subsequent analyses. Reaction time analyses included only correct responses. Naming responses that were not related to the task but that triggered the voice key (coughs, sniffs, etc.) were removed from subsequent analyses.

Training. Training accuracies and reaction times were submitted to a 2x2x2x8 ANOVA, with phonological access condition at training (Promoted or Impeded) and counterbalancing list entered as between subjects factors, and wordlikeness (high and low) and training block (1 through 8) entered as within subjects factors. Means are displayed in Figures 6 and 7. There was no main effect of the phonological access condition in the accuracy results ($p = .722$). The reaction time results were contrary to predictions: responses during training were reliably faster when participant heard auditory information that was unrelated to the text on the screen (Impeded) than when they simultaneously heard the pseudoword that they were viewing (Promoted) ($F(1,50) = 12.492$, $p = .001$).

As was seen in the prior two experiments, there was a main effect of training block in both the accuracy ($F(7,350) = 64.018$, $p < .001$) and reaction time analyses ($F(7,350) = 19.772$, $p < .001$), with performance faster and more accurate at the end of training than at the beginning. There was a main effect of wordlikeness in the training results, with participants responding faster ($F(1,50) = 8.324$, $p = .006$, $\eta_p^2 = .143$) and with reliably fewer errors ($F(1,50) = 4.049$, $p = .05$, $\eta_p^2 = .075$) on trials with high wordlikeness items than low. There were no reliable interactions between training block, wordlikeness, or phonological access condition in either the accuracy or reaction time analyses. Examination of the phonological access conditions individually revealed that there was no wordlikeness effect in the accuracy data of the Impeded condition (*p*=.516), but that responses to high wordlikeness items were reliably more accurate the Promoted condition (*p*=.027), providing some evidence to suggest that the manipulation had impacted phonological access during learning.

Naming. Naming reaction times and accuracies were submitted to a 2x2x2x2 ANOVA, with phonological access condition and training list entered as between subjects factors, and wordlikeness (high and low) and training status (trained and untrained) entered as within subjects factors. Means are reported in Tables 7 and 8. There was no reliable main effect of phonological access condition on naming performance in either the accuracy or the reaction time analyses. There were no differences in naming performance between high and low wordlikeness in terms of accuracy (p = .965) or reaction time (p = .100). There was a main effect of training status in the naming reaction time analysis ($F(1,50) = 35.081$, $p < .001$, $\eta_p^2 = .412$), with trained pseudowords named more quickly than untrained. No differences in naming performance on trained and untrained items was evident in the accuracy results (*p*=.101).

Semantic Identity. Reaction time and accuracy data from the semantic identity task were submitted to a 2x2x2 ANOVA with phonological access condition (Promoted or Impeded) and counterbalancing list entered as between subjects factors, and wordlikeness entered as a within subjects factor. Means are reported in Table 9. There were no main effects of phonological access condition in the reaction time or accuracy data. This was also true in post hoc analyses in which responses to the target and the within-category distractor were counted as correct. There was a main effect of wordlikeness on reaction time, with participants reliably faster at matching high wordlikeness items to their picture identity than low ($F(1,50) = 13.232$, $p = .001$), but there were no reliable wordlikeness effects on task accuracy ($p = .123$).

Discussion

As was seen in Experiment 2, participants in Experiment 3 were faster and more accurate during training on high PD wordlikeness items. There was weak evidence from the training data and no evidence from the post-training tasks that the phonological access manipulation had a significant effect on participants' sensitivity to the phonological regularities of the stimuli. The faster reaction times for high and low wordlikeness items in the Impeded phonological access condition in the learning reaction time data is counter to predictions, as interfering with access to phonology was predicted to lead to a less stable representation and subsequently compromise performance relative to the Promoted condition. While at odds with the results from some studies in which simultaneous presentation facilitated word learning (Ehri & Rosenthal, 2007; Escudero et al., 2008; Rosenthal & Ehri, 2011), those studies involved developing readers, or individuals learning words containing unfamiliar phonology. The advantage for simultaneous presentation found in Kaushansky and Marian (2009) was only for individuals who were proficient in a second language, and all of the participants in Experiment 3 described themselves as only speaking American English. Comments made by participants after they completed the experiment provided some insight. As observed in Experiments 1 and 2, a number of them said the words out loud to themselves as they went along, or reported that they said the words "in their heads" during the learning blocks. Many in the Impeded condition reported that they simply "tuned out" the conflicting auditory information. By their reports, they are practiced at this as they frequently have to disregard what they hear (television programs, music, conversations, etc.) when they study. This suggests that introducing irrelevant auditory stimuli, rather than blocking phonological access, may have caused many of the participants to engage in the phonology more intentionally, and increased their attentional focus to inhibit the irrelevant information during the task. It is also possible that the participants in the Promoted condition implicitly waited for the spoken word to be completed before they responded, which may have slowed them down relative to the Impeded condition in which participants ignored the spoken pseudoword.

General Discussion

Three experiments were conducted to evaluate predictions about the roles of prior knowledge as instantiated by wordlikeness and the role of the latent phonological form of a word during visual word learning. Based on the proposed hybrid model of word learning, I hypothesized that as skilled readers are tuned to the orthographic and phonological properties of their native language, this knowledge would influence behavior early in the process of learning a new word. I predicted that both orthographic and phonological typicality would facilitate visual word learning, given the evidence that phonology is automatically accessed during visual word processing, even when the task does not require the phonological code to be generated overtly. Considering evidence from second language learning and novel word learning within a language and the structure of the proposed hybrid model of word learning, I predicted that greater orthographic and phonological typicality (wordlikeness) would be associated with better learning of meaning associates for written words as well as faster and more accurate naming of learned words for both the orthographically different and phonologically different conditions.

The role of prior knowledge in word learning

The training results of Experiments 1, 2 and 3 supported the first hypothesis that prior knowledge, in this case in the form of knowledge of the orthographic and phonological regularities of a speaker's language, influences learning behavior early in the process of learning the meaning of a new word. The finding in the first experiment that trained and untrained high wordlikeness pseudowords were named faster and more accurately than their less probable untrained counterparts is consistent with the claim that the learners' knowledge of their language is available and brought to bear even on the first encounter with a word form that is not instantiated in long term memory. This informs the line of investigation regarding the interaction of long-term memory with novel words. Prior studies (e.g. Gaskell & Dumay, 2003; Leach & Samuel, 2007) explored the reverse flow of information and focused on the influence of a learned word on the performance of existing words during specific lexical tasks. They saw evidence for an effect of the newly learned word only after a period of consolidation. The results of this dissertation demonstrated an effect of long-term memory/known words on the first contact with a novel word during naming and during the process of associating a meaning with the novel word form. This suggests that consolidation is not required for an interaction between long-term memory and the new word, but it may be critical in the direction of that interaction. It is not yet clear what effect consolidation of new learning would have on the differences between high and low wordlikeness in additional training epochs and naming behavior across additional days of training. As the high wordlikeness items are more typical of words already in long-term memory, it is possible that they may be more easily assimilated. On the other hand, the less typical, low wordlikeness items may show more of a benefit from consolidation, with a narrowing of the gap between high and low wordlikeness items after a period of consolidation. And, as reported by Storkel & Lee (2011) in their spoken word study, the advantage of high vs. low wordlikeness may change over time. They reported more accurate referent identification of items from sparse phonological neighborhoods on the day of training, but better retention one week post-training of referent identity of items from dense phonological neighborhoods.

Influence of the latent code

The results of this study yielded evidence that both the input modality (orthography) and the underlying phonology influence early receptive and expressive word learning. Support for the claim that phonology was engaged during visual word learning comes from the results of the naming tasks that were completed immediately after training. In Experiments 1 and 2, trained words were named faster (and in Experiment 1 more accurately) than untrained words. This facilitation can be interpreted as the consequence of repeated elicitations of the phonological forms of the novel word during the decoding process that likely occurred during training, perhaps representing a subvocal rehearsal of naming aloud. Further evidence comes from the training results on the PD stimuli in Experiments 2 and 3. In those experiments, better learning of meaning was associated with written words that had more highly probable phonological forms. This parallels Storkel's findings (2001; 2003) that greater phonological probability facilitated (expressive and receptive) spoken word learning. As neighborhood size and bigram/biphone frequency were intentionally covaried in the present experiments, the results of this study do not allow us to infer a possible lexical or sublexical locus for the wordlikeness effects.

There was no benefit for high wordlikeness during oral reading of trained or untrained phonologically different (PD) stimuli in Experiments 2 and 3. It is possible that reading aloud may depend more on the characteristics of the orthography, with faster and more accurate naming associated with more probable orthographic items, as seen in Experiment 1.

In summary, the characteristics of a word or pseudoword that influence language processing and novel word learning include more than just the characteristics of the encountered form. The rapid acquisition of the meanings for novel words has been associated with higher quality, more stable representations that arose from information from the input code as well as the latent code. The evidence reviewed suggests that the representation that is formed when readers learn new words and the ease with which that representation can be accessed upon repeated encounters may depend on the characteristics of the information in the input code (auditory-phonologic or visual-grapheme) as well as the quality of the representations in the latent code that may have been automatically activated during the learning encounter. When prior knowledge is limited, as with developing readers or second language learners encountering a non-native contrast, explicit provision of the latent code (Ehri & Rosenthal, 2007; Escudero et al., 2008; Kaushansky & Marian, 2009) and or requiring the learner to produce the latent code (Rosenthal & Ehri, 2011) have been associated with better word learning.

Reading theory and word learning

Some well-developed theories of word learning have only addressed spoken word learning (c.f. Davis and Gaskell, 2009; Gupta and Tisdale, 2009), and have not taken into account the influence of literacy in adult skilled language users. For skilled readers, those models omit the important and mandatory influence of orthography during language processing. Castro-Caldas, Petersson, Reis, Stone-Elander, and Ingvar (1998) compared the performance of functionally illiterate individuals with their literate peers on a pseudoword repetition task, and demonstrated that literacy affected the behavioral performance and brain activations during pseudoword repetition. This tuning of how the brain processes spoken language by the acquisition of reading skill provides evidence that it is not possible to process one code without activating the other to some extent, supporting the claims from behavioral studies of spoken word (c.f. Seidenberg & Tanenhaus, 1979; Chereau, et al, 2007) and visual word processing (c.f. Van Orden, 1987; Lukatela & Turvey, 1990). As Ehri (1987) commented: " If one is studying how children's language develops or how adults process language, consideration must be given to the influence of knowing how to read and spell." Models of reading are fairly well suited to address this engagement of both codes during word learning and processing, regardless of input modality. The Gupta and Tisdale (2009) model of word learning does posit a role for long-term memory (existing knowledge), and the trained network is tuned to the statistical regularities of the spoken language. In this way, existing knowledge (the state of the system) interacts with novel input during word learning. Encounters with new word input in the Triangle Model also involve new information being processed by a network that has been tuned to reflect prior experience. The Triangle Model includes semantics, phonology, and orthography in the theoretical model, but not all possible combinations of input and output have been computationally implemented.

Much remains to be done to develop an account of word learning that includes connections between semantics, orthography, and phonology to describe both comprehension of meaning and spoken and written output. The proposed hybrid model extends beyond the connections between orthography and phonology and considers the influences of the orthographic and phonological constituents during visual word learning. This allows for testable predictions about the influences of specific word characteristics, which can shape the development of a comprehensive model of word learning.

Limitations and future directions

While a wordlikeness effect was evident in paired associate learning, this paradigm explores only one kind of contact that adults have with unknown words. This study looks at single words that represent nouns outside of any context. In functional situations within their native language, adult readers learn words from a variety of word classes in sentences and paragraphs that create a context, and rarely if ever study picture-word associates or even memorize definitions, outside of a classroom. It is unknown what effect variability in wordlikeness would have when meaning is unknown and has to be inferred from context, or when the meaning is more abstract or represents a different part of speech than nouns. Additionally, these results only apply to learning words in a language with orthotactic and phonotactic properties comparable to English.

The proposed hybrid model of word learning predicts a role for the latent code in learning a novel word form and associating it with meaning. The Self-teaching hypothesis (Jorm & Share, 1983) posits the utility of phonological recoding as a mechanism for learning new words, and the results of naming tasks on Experiments 1 and 2 of this dissertation provide evidence that phonological information accessed during word learning impacted naming performance on trained items that had more recoding opportunities as compared to untrained items. And in Experiment 2, more probable phonological forms were associated with better learning of semantic associates, supporting the hypothesis that the latent phonological code impacts visual word learning. The semantic identity employed in Experiments 1, 2, and 3 was less informative than hoped, perhaps due to response limitations of using a forced alternative choice task with four choices. A forced alternative choice task with only two choices may have been more sensitive to the wordlikeness manipulation, as it would permit more efficient keyboard responses.

To more fully test the prediction that the latent code influences novel word learning, the methods of the present study could be extended to an experiment in which the OD and PD nonword stimuli were learned in a spoken word context, with the OD stimuli representing a manipulation of the latent code. The hybrid model would predict that spoken learning would be facilitated for items with higher quality, more wordlike orthographic constituents. Additionally, post-training measures could include measures of the production of orthography (e.g. spelling) and phonology (e.g. naming). Chalmers and Burt (2008) commented that a spelling measure would be required to appropriately assess knowledge of orthography, but Ehri's point that spelling places different demands on memory than reading (Ehri, 2000) is well-taken, and spelling production performance and spelling recognition performance tap different memory functions. In theory, the results of orthographic assessment following spoken word learning would inform the claims of the proposed model that the latent orthographic code has a measurable effect on learning. Assessing spelling post-training could also inform the interpretation of the pattern of results seen in naming by providing an additional means to measure post-training output. However, assessment of orthographic knowledge can be problematic. In the case of completing a spelling task following spoken word learning, comparisons to naming results following written word learning could be confounded by the fact that mappings from phonology to orthography are less systematic than mappings from orthography to phonology. Consequently, asymmetries in the comparison between input-output mismatch productions may be driven by the tasks, rather than the word characteristics.

In summary, the results of the present study support the claim that for skilled readers, the prior knowledge of the orthographic and phonological regularities of their language influences performance during novel visual word learning, with better learning of word/meaning pairs associated with more probable word forms. The results also provided evidence that phonology and orthography are inextricably bound in skilled readers such that both codes influence performance early in visual word learning, even on the first contact with a novel written word. However, the codes are not redundant. More probable orthographic forms in Experiment 1 were associated with more accurate performance during the training task, while responses during training were more accurate and faster for the more probable phonological forms in Experiments 2 and 3. In terms of naming, there was no advantage for more probable phonological forms, but the more probable orthographic forms in Experiment 1 were named faster and more accurately than the less probable low wordlikeness items. The results of this dissertation suggest that models of word learning in skilled language users need to expand their accounts to address the interrelationship between orthographic and phonological knowledge and their separable contributions in order to capture the relevant phenomena in word learning and make reasonable assumptions and predictions about adult skilled language users. To this end, I propose extending models of reading acquisition to address questions related to spoken and written word learning in language users who have experience with print.

References

Bailey, C., Manis, F., Pedersen, W, & Seidenberg, M. (2004). Variation among developmental dyslexics: Evidence from a printed-word learning task. *Journal of Experimental Child Psychology*, *87,* 125-154.

Bartolotti, X., & Marian, V. (2014) Wordlikeness and novel word learning. Paper presented at the annual meeting of the Cognitive Science Society, Quebec City, Canada. Paper retrieved from https://mindmodeling.org/cogsci2014/papers/036/paper036.pdf

Braun, M., Hutzler, F., Ziegler, J., Dambacher, M., & Jacobs, A. (2009). Pseudohomophone effects provide evidence of early lexico-phonological processing in visual word recognition. *Human Brain Mapping, 30*, 1977-1989.

Burt, J., & Blackwell, P. (2008). Sound-spelling consistency in adults' orthographic learning. *Journal of Research in Reading, 31*, 77-96.

Castro-Caldas, A., Petersson, K.M., Reis, A., Stone-Elander, S., & Ingvar, M. (1998). The illiterate brain: Learning to read and write during childhood influences the functional organization of the adult brain. *Brain*, *121*, 1053-1063.

Chalmers, K., & Burt, J. (2008). Phonological and semantic information in adults' orthographic learning. *Acta Psychologica, 128*, 162-175.

Chéreau, C., Gaskell, M.G., & Dumay, N. (2007). Reading spoken words: Orthographic effects in auditory priming. *Cognition, 102*, 341-360.

Collisson, B., Aicher, K. A., Arthur, D., & Rueckl, J. G. (in preparation). Influences of wordlikeness and context in novel word learning.

Davis, M., Di Betta, A.M., Macdonald, M., & Gaskell, G. (2009). Learning and consolidation of novel spoken words. *Journal of Cognitive Neuroscience, 21*, 803-820.

Davis, M., & Gaskell, G. (2009). A complementary systems account of word learning: Neural and behavioural evidence. *Philosophical Transactions of the Royal Society B, 364*, 3773-3800.

de Groot, A. (2006). Effects of stimulus characteristics and background music on foreign language vocabulary learning and forgetting. *Language Learning, 56*, 463-506.

de Groot, A., & Keijzer, R. (2000). What is hard to learn is easy to forget: The roles of word concreteness, cognate status, and word frequency in foreign-language learning and forgetting. *Language Learning, 50*, 1-56.

Ehri, L. (2000). Learning to read and learning to spell: Two sides of a coin. *Topics in Language Disorders, 20*, 19-36.

Ehri, L. & Rosenthal, J. (2007). Spellings of words: A neglected facilitator of vocabulary learning. *Journal of Literacy Research, 39*(4), 389-409.

Ellis, N., & Beaton, A. (1993). Psycholinguistic determinants of foreign language learning. *Language Learning, 43*, 559-617.

Escudero, P., Hayes-Harb, R., & Mitterer, H. (2008). Novel second-language words and symmetric lexical access. *Journal of Phonetics, 36*, 345-360.

Feldman, A. & Healy, A. (1998). Effect of first language phonological configuration on lexical acquisition in a second language. In A. Healy, A., & L. Bourne (Eds.), *Foreign Language Learning: Psycholinguistic Studies on Training and Retention* (pp. 57-76). Mahwah, NJ: Lawrence Ehrlbaum Associates, Inc.

Gaskell, M. G., & Dumay, N. (2003). Lexical competition and the acquisition of novel words. *Cognition, 89*, 105-132.

Gaskell, M. G., & Ellis, A. (2009). Word learning and lexical development across the lifespan. *Philosophical Transactions of the Royal Society, 364*, 3607-3615.

Gathercole, S., Willis, C., Emslie, H., & Baddeley, A. (1991). The influences of number of syllables and wordlikeness on children's repetition of nonwords. *Applied Psycholinguistics*, *12,* 349-367.

Gupta, P., & Tisdale, J. (2009). Word learning, phonological short-term memory, phonotactic probability and long-term memory: Towards an integrated framework. *Philosophical Transactions of The Royal Society, 364,* 3755-3771.

Harm, M.W. & Seidenberg, M.S. (2004). Computing the meanings of words in reading: Cooperative division of labor between visual and phonological processes. *Psychological Review*, *111*, 662-720.

Howland, K., & Liederman, J. (2013). Beyond decoding: Adults with dyslexia have trouble forming unified lexical representations across pseudoword learning episodes. *Journal of Speech, Language, and Hearing Research, 56*, 1009-1022.

Jorm, A.F. & Share, D.L. (1983). Phonological recoding and reading acquisition. *Applied Psycholinguistics*, *4*(2), 103-147.

Kaushanskaya, M., & Marian, V. (2009). The bilingual advantage in novel word learning. *Psychonomic Bulletin & Review, 16*, 705-710.

Larsen, J. & Baddeley, A. (2003). Disruption of verbal STM by irrelevant speech, articulatory suppression, and manual tapping: Do they have a common source? *The Quarterly Journal of Experimental Psychology Section A - Human Experimental Psychology, 56,* 1249-1268.

Leach, L. & Samuel, A. (2007). Lexical configuration and lexical engagement: When adults learn new words. *Cognitive Psychology, 55,* 306-353.

Lukatela, G., Lukatela K., & Turvey, M. T. (1993). Further evidence for phonological constraints on visual lexical access: TOWED primes FROG. *Perception and Psychophysics, 53,* 461-466.

Lukatela, G., & Turvey, M. T. (1990). Automatic and pre-lexical computation of phonology in visual word identification. *European Journal of Cognitive Psychology, 2,* 325-343.

Lukatela, G., & Turvey, M. T. (1991). Phonological access of the lexicon: Evidence from associative priming with pseudohomophones. *Journal of Experimental Psychology: Human Perception and Performance, 17,* 951-966.

Lukatela, G., & Turvey, M. T. (1994a). Visual lexical access is initially phonological: 1. Evidence from phonological priming by words, homophones and pseudohomophones. *Journal of Experimental Psychology: General, 123,* 107-128.

Lukatela, G., & Turvey, M. T. (1994b). Visual lexical access is initially phonological: 2. Evidence from phonological priming by homophones and pseudohomophones. *Journal of Experimental Psychology: General*, *123*, 331-353.

McKague, M., Davis, C., Pratt, C., & Johnston, M. (2008). The role of feedback from phonology to orthography in orthographic learning: An extension of item-based accounts. *Journal of Research in Reading, 31,* 55-76.

McKay, A., Davis, C., Savage, G., & Castles, A. (2008). Semantic involvement in reading aloud: Evidence from a nonword training study. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *34*, 1495-1517.

Nelson, J. R., Balass, M., & Perfetti, C. A. (2005). Differences between written and spoken input in learning new words. *Written Language & Literacy, 8*(2), 25-44.

Perfetti, C. (2007). Reading ability: Lexical quality to comprehension. *Scientific Studies of Reading, 11*, 357-383.

Perfetti, C.A., & Hart, L. (2002). The lexical quality hypothesis. In L. Vehoeven. C. Elbro, & P. Reitsma (Eds.), *Precursors of functional literacy* (pp. 189-213). Amsterdam/Philadelphia: John Benjamins.

Perre, L., Pattamadilok, C., Montant, M., & Ziegler, J. (2009). Orthographic effects in spoken language: On-line activation or phonological restructuring? *Brain Research, 1275*, 73-80.

Rastle, K., Harrington, J., & Coltheart, M. (2002). 358,534 nonwords: The ARC Nonword Database. *Quarterly Journal of Experimental Psychology, 55A*, 1339-1362.

Rastle, K., McCormick, S., Bayliss, L., & Davis, C. (2011). Orthography influences the perception and production of speech. *Journal of Experiment Psychology: Learning, Memory, and Cognition*, *37*, 1588-1594.

Ricketts, J., Bishop, D., & Nation, K. (2009). Orthographic facilitation in oral vocabulary acquisition. *The Quarterly Journal of Experimental Psychology, 62*(10), 1948-1966.

Rosenthal, J. & Ehri, L. (2011). Pronouncing new words aloud during the silent reading of text enhances fifth grader's memory for vocabulary words and their spellings. *Reading and Writing, 24*, 921-950.

Sandak, R., Mencl, W., Frost, S. J., Rueckl, J. G., Katz, L., Moore, D. L. et al. (2004). The neurobiology of adaptive learning in reading: A contrast of different training conditions. *Cognitive, Affective & Behavioral Neuroscience, 4*(1), 67–88.

Seidenberg, M., & McClelland, J. (1989). Visual word recognition and pronunciation: A computational model of acquisition, skilled performance, and dyslexia. In Galaburda, Albert M. (Ed.), *From reading to neurons* (pp. 255-303). Cambridge, MA, US: The MIT Press.

Seidenberg, M., & Tanenhaus, M. (1979). Orthographic effects on rhyme monitoring. *Journal of Experimental Psychology: Human Learning and Memory, 5,* 546-554.

Service, E., & Craik, F.I.M. (1993). Differences between young and older adults in learning a foreign vocabulary. *Journal of Memory and Language*, *32*, 608-623.

Storkel, H. (2001). Learning new words: Phonotactic probability in language development. Journal of Speech, Language, and Hearing Research, 44, 1321-1337.

Storkel, H. (2003). Learning new words II: Phonotactic probability in verb learning. Journal of *Speech, Language, and Hearing Research, 46*, 1312-1323.

Storkel, H., Armbrüster, J., Hogan, T. (2006). Differentiating phonotactic probability and neighborhood density in adult word learning. *Journal of Speech, Language, and Hearing Research, 49,* 1175- 1192.

Storkel, H., & Lee, S. (2011). The independent effects of phonotactic probability and neighbourhood density on lexical acquisition by preschool children. *Language and Cognitive Processes, 26*, 191-211.

Taft, M., Castles, A., Davis, C., Lazendic, G., & Nguyen-Hoan, M. (2008). Automatic activation of orthography in spoken word recognition: Pseudohomograph priming. *Journal of Memory and Language, 58,* 366–379.

Van Orden, G.C. (1987). A ROWS is a ROSE: Spelling, sound, and reading. *Memory & Cognition*, *15*, 181-198.

Ventura. P., Morias, J., Pattamadilok, C., & Kolinsky, R. (2004). The locus of the orthographic consistency effect in auditory word learning. *Language and Cognitive Processes, 19*, 57-95.

Vitevitch, M.S. & Luce, P.A. (2004) A web-based interface to calculate phonotactic probability for words and nonwords in English. *Behavior Research Methods, Instruments, and Computers, 36*, 481-487

Yates, M. (2005). Phonological neighbors speed visual word processing: Evidence from multiple tasks. *Journal of Experiment Psychology: Learning, Memory and Cognition. 31*, 1385-1397.

Yates, M., Locker, L., & Simpson, G. (2004). The influence of phonological neighborhood on visual word perception. *Psychonomic Bulletin and Review, 11*, 452-457.

Table 1

Orthographically Different (OD) Wordlikeness Characteristics

		NON	SFON	BigrTp	BigrTn	NPN	SFPN	MBiph	NP
High wordlikeness	Mean	6	421	130	104193	15	858	0.0025	3.38
	Min	4	101	80	24838	8	237	0.0009	3.00
	Max	12	4126	191	320759	25	2620	0.0057	4.00
Low wordlikeness	Mean	0	0	40	9576	15	805	0.0025	3.28
	Min	0	0	5	681	8	165	0.0009	3.00
	Max	0	0	69	17996	25	2791	0.0064	4.00

Note. Mean values for orthographic and phonological properties of pseudowords in Experiment 1. NON: number of orthographic neighbors; SFON: summed frequency of orthographic neighbors; BigrTP: bigram frequency (type); BigrTN: bigram frequency (token); NPN: number of phonological neighbors; SFPN: summed frequency of phonological neighbors; MBiph: mean biphone probability; NP: number of phonemes.

Table 2

Experiment 1 Naming

		Trained		Untrained	
		Accuracy	RT (ms)	Accuracy	RT (ms)
High wordlikeness	Mean	.91	668	.88	705
Low wordlikeness	Mean	.85	739	.80	785

Table 3

Experiment 1 Semantic Identity Accuracy and Reaction Times

		Accuracy	RT (ms)
High wordlikeness	Mean	.85	2158
Low wordlikeness	Mean	.85	2178

Table 4

Phonologically Different (PD) Wordlikeness Characteristics

		NON	SFON	BigrTp	BigrTn	NPN	SFPN	MBiph	NP
High wordlikeness	Mean	2	26	85	28932	21.55	2860.425	0.0029	3.15
	Min	1	1	40	10523	12	746	0.0015	3.00
	Max	5	111	125	55426	36	15439	0.0116	4.00
Low wordlikeness	Mean	1.975	29.175	82	32161.2	2.65	15.25	0.0009	3.7
	Min	1	1	49	9116	0	0	.0000	3.00
	Max	7	189	133	65373	4	97	0.0014	4.00

Note. Mean values for orthographic and phonological properties of pseudowords in Experiment 2. NON: number of orthographic neighbors; SFON: summed frequency of orthographic neighbors; BigrTP: bigram frequency (type); BigrTN: bigram frequency (token); NPN: number of phonological neighbors; SFPN: summed frequency of phonological neighbors; MBiph: mean biphone probability; NP: number of phonemes.

Table 5

Experiment 2 Naming

		Trained		Untrained	
		Accuracy	RT (ms)	Accuracy	RT (ms)
High wordlikeness	Mean	.89	673	.90	743
Low wordlikeness	Mean	.88	661	.91	704

Table 6

Experiment 2 Semantic Identity Accuracy and Reaction Times

		ACC	RT (ms)
High wordlikeness	Mean	.83	2164
Low wordlikeness	Mean	.81	2252

Table 7

Experiment 3 Naming Accuracy

		Trained		Untrained	
		Impeded	Promoted	Impeded	Promoted
High wordlikeness	Mean	.90	.92	.91	.90
Low wordlikeness	Mean	.92	.92	.91	.88

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Table 8

Experiment 3 Naming Reaction Times (in milliseconds).

		Trained		Untrained	
		Impeded	Promoted	Impeded	Promoted
High wordlikeness	Mean	708	661	756	686
Low wordlikeness	Mean	706	656	741	669

Table 9

Experiment 3 Semantic Identity Accuracy and Reaction Times

		Impeded		Promoted	
		Accuracy	RT (ms)	Accuracy	RT (ms)
High wordlikeness	Mean	.81	2211	.80	2300
Low wordlikeness	Mean	.75	2329	.81	2465

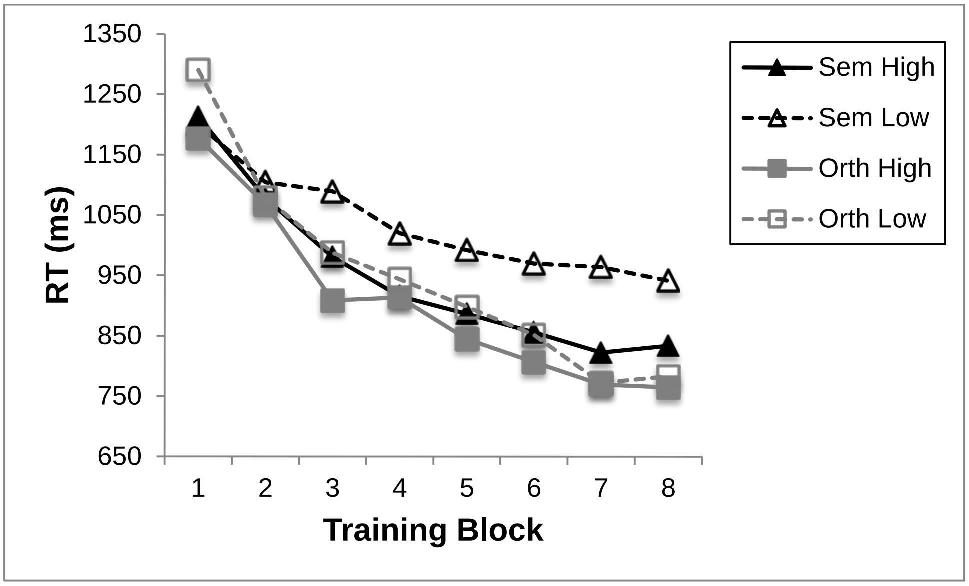

Figure 1. Mean reaction time by training block (Collisson et al., in preparation).

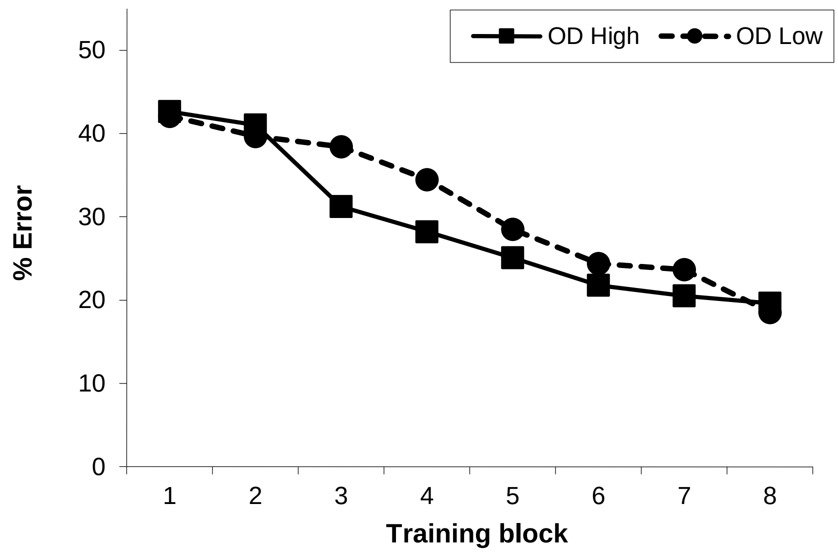

Figure 2. Experiment 1 mean % error by training block

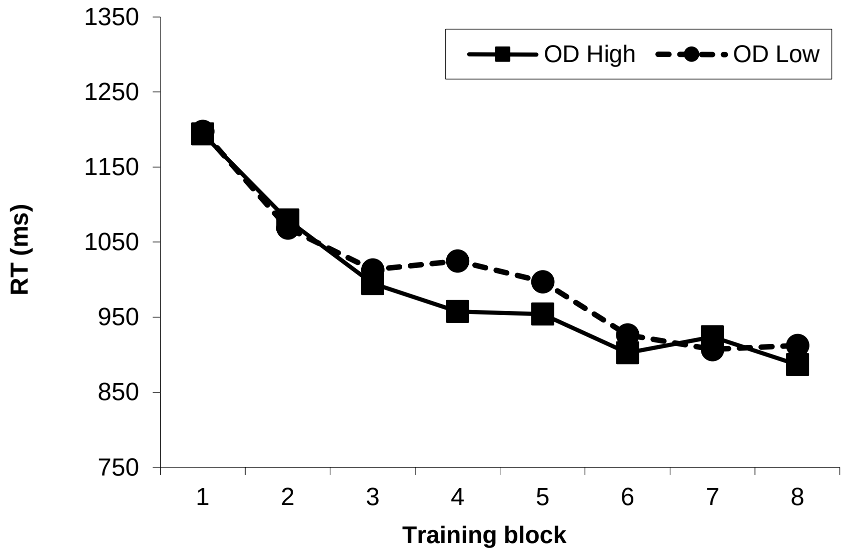

Figure 3. Experiment 1 mean reaction time by training block.

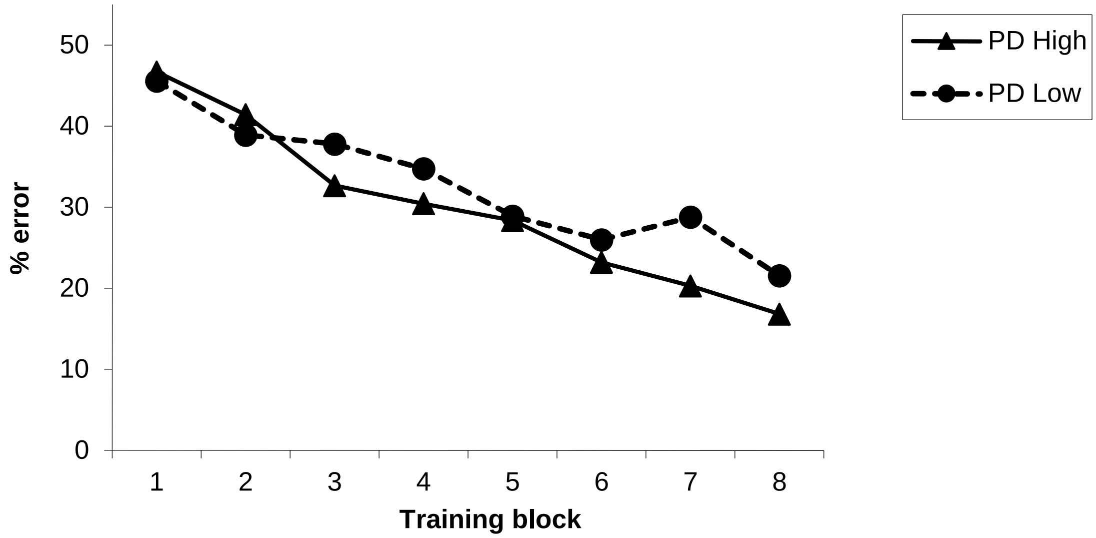

Figure 4. Experiment 2 mean % error by training block.

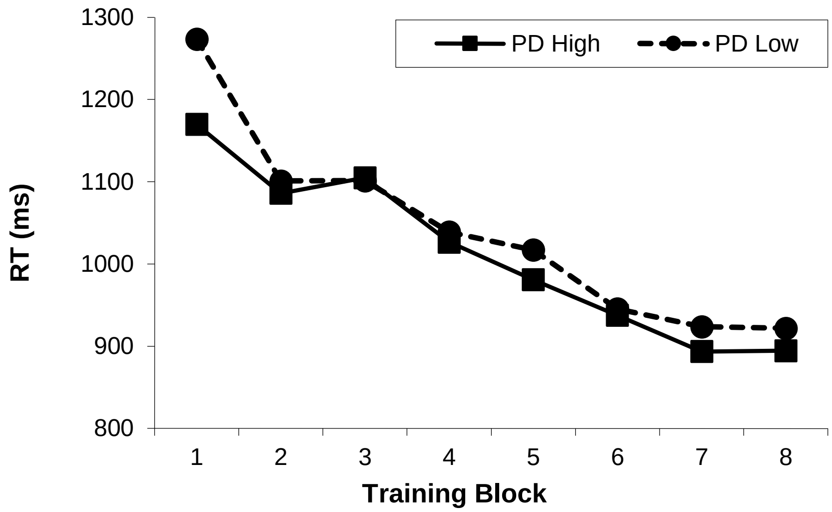

Figure 5. Experiment 2 mean reaction time by training block.

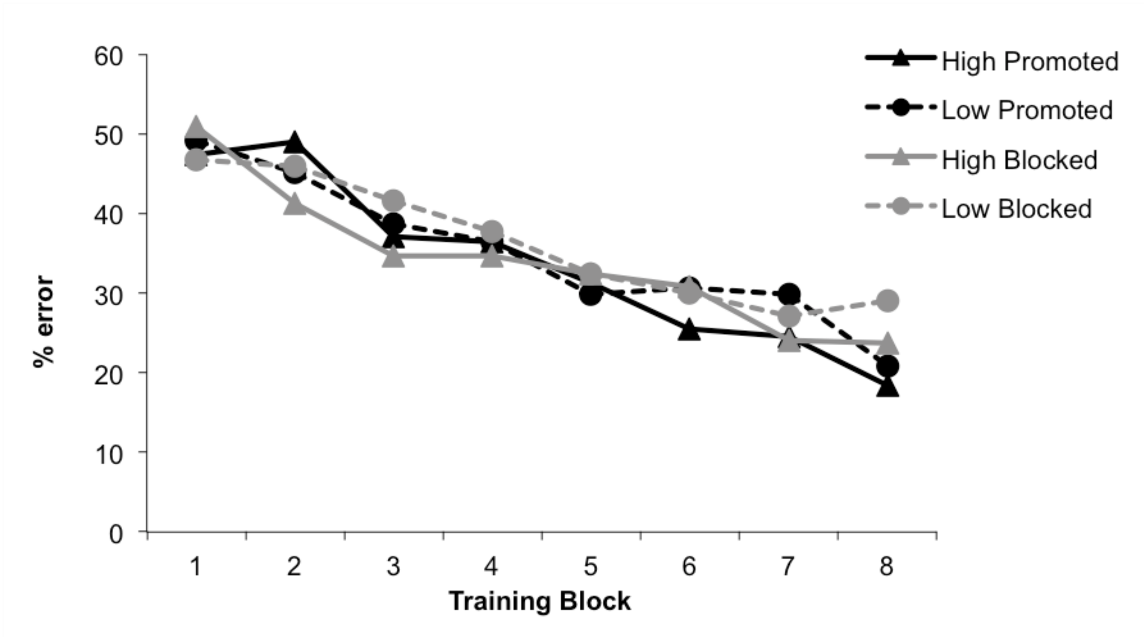

Figure 6. Experiment 3 mean % error by training block and condition.

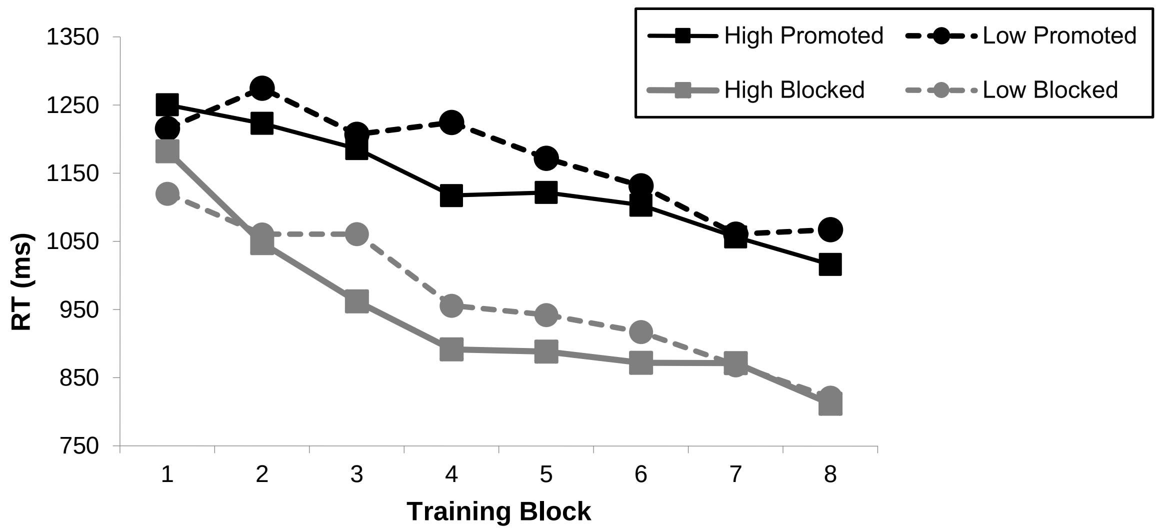

Figure 7. Experiment 3 mean reaction times by training block and condition.