Orthographic and phonological neighborhood effects within a priming context

BY

April Fugett-Fuller

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Chairperson

Committee members* ______________________*

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Date defended: ________________

The Dissertation Committee for April Fugett-Fuller certifies
that this is the approved version of the following dissertation:

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Committee:

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Chairperson*

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Date approved:__________________________

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ABSTRACT

Two experiments were completed investigating orthographic neighborhood size in the context of phonological neighborhood size and priming, at various SOAs. Experiment 1 exhibited that words from larger phonological neighborhoods were processed more quickly than those that are not. Also, targets were responded to more quickly at long SOAs and being from a large orthographic neighborhood was facilitative at the 500 ms SOA. There was a three-way interaction between phonological and orthographic neighborhood size and relatedness qualified by two two-way interactions between orthography and phonology and phonology and relatedness. Experiment 2 employed a manipulation of the prime with the same stimuli as Experiment 1. Experiment 2 also exhibited main effects of priming and of SOA. There was also a significant three-way interaction between orthographic and phonological neighborhood size and relatedness, whereby, in the related condition, words from both a small orthographic and a small phonological neighborhood were processed more quickly.

CHAPTER I

INTRODUCTION

A growing topic in word recognition research concerns neighborhood effects. Typically, neighborhoods (as defined for semantic, phonological, and orthographic representations) are defined as consisting of items that can be created from an original item by changing a single "feature." The total number of words that can be created by changing a single feature (whether it be orthographic or phonologic) is the neighborhood size of the original word. For example, phonological neighborhoods can be defined by changing any single phoneme (where the phoneme is the feature) within a target word to create a new word like "day" to "bay" (Peereman & Content, 1997). Likewise, orthographic neighborhoods are defined as the set of words that can be created from the target word by changing a single letter (and has been labeled "N" by Coltheart, Davelaar, Jonasson & Besner, 1977). For example, to create the orthographic neighborhood for a given word, one would take the word and change one letter at a time to create a list of all possible words that could be created by going through this process. "Day" and "bay" are also orthographic neighbors (as are "say" and "boy" to "bay"). The definition of a semantic neighborhood is one that is much debated (see Shelton & Martin, 1992; and Stolz & Besner, 1998). A semantic neighbor can be a set of words very similar in meaning (e.g., "toad" and "frog" where both are similarly defined). However, a semantic neighbor can also be defined in terms of associations like "frog" and "wart."

Specifically, the focus of this paper is the influence of orthography on visual word recognition. Previous literature suggests that orthographic neighborhoods can be either facilitative (larger neighborhoods speed up processing of visually presented words) or inhibitory (larger neighborhoods can slow down processing). This paper seeks to understand these opposing effects and under what circumstances they might appear.

The primary focus will be on orthography, but there will also be some discussion of phonological effects. Even though orthographic and phonological neighborhoods are very different things, the effects created through their manipulation are often unclear because of the degree of overlap between the two and the potential for mediating effects (Reimer, Brown, & Lorsbach, 2001). In other words, target words that are orthographically related also tend to be phonologically related. For example, if the word of interest is “day,” by changing “d” to “b,” an orthographic neighbor has been created. Further, the new orthographic neighbor is also a phonological neighbor because “day” and “bay” only differ by a single phoneme. If the targets of an experiment consisted of words with this composition, one would not be able to determine if the effect was phonological, orthographic, or some interaction of the two.

In addition to orthography and phonology, it is important to consider semantics. A person reads to gain meaning. The study of visual word recognition is largely an exercise in understanding how reading takes place, and ultimately the goal of reading is understanding. Orthography and phonology are an important part of visual word recognition; however, studying orthography and phonology alone would be like checking the cover and pictures in a novel. Information is gained by doing this, but the nuances of the book—the meaning held within the novel—would be lost. It is important to look at all three major components (orthography, phonology, and semantics) of visual word recognition to obtain a clearer picture of how visual word recognition works.

Models of Visual Word Recognition

Studies have shown that neighborhood size affects the speed of word recognition. Both Andrews (1997) and Perea and Rosa (2000) conducted literature reviews on studies dealing with visual word recognition. They seem to be base their conclusions about both neighborhood (N) and neighborhood frequency (FN, the frequency of the individual neighbor) on how the effect (either inhibition or facilitation) fits into selected models of word recognition. For example, if model X cannot account for inhibition, there is a problem with all of the experiments that show inhibition. This seems to be a backward approach to word recognition. A model should be presented and then tested with experimental evidence. If the model and experimental results (across multiple experiments) are not consistent then the model either needs to be revised to account for the experimental data or rejected. This is not to exclude the possibility that there is conflicting evidence about the same phenomenon. If this were the case, a model should have problems predicting conflicting results for the same subset of stimuli.

The models of most interest in this paper are parallel distributed processing (PDP) “triangle” model, (see Harm & Seidenberg, 2004; and Seidenberg & McClelland, 1989) the interactive activation (IA) models, (see Grainger & Jacobs, 1996; and McClelland & Rumelhart, 1981; Reimer et al., 2001) and the dual route cascaded (DRC) model (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001). Even though these are not the only models of visual word recognition, the PDP and IA models have tried to account for orthographic neighborhood effects (Jacobs & Grainger, 1994), and the DRC model is a distinct competitor to them.

Jacobs and Grainger (1994) conducted a comprehensive review of models of visual word recognition. In their paper, they summarized the types of models and the tasks involved in studying each of the models. Eight of the 15 models they presented attempted to account for orthographic neighborhood effects. Even though arguments exist that orthographic neighborhood effects could be task specific, the models examined by Jacobs and Grainger relied on data from all three major word recognition tasks: perceptual identification, lexical decision, and naming. In short, several models attempt to account for N effects in the contexts of varying tasks.

Interactive Activation Model

Grainger and Jacobs (1996) presented a comprehensive overview of the manner in which an interactive-activation (IA) model could account for orthographic neighborhood effects. The particular example of an IA model that they describe is the multiple read-out model. The multiple read-out model states that a response is made when an appropriate code reaches a critical activation level (Grainger & Jacobs, 1996). In other words, upon visual recognition, codes are generated at a unit level (selection of a specific lexical item) and a global level (general activity of nodes surrounding a specific lexical item). These codes can also be thought of as levels of activation for a given unit or for global activation. For any given trial, once activation reaches a certain level, the participant reacts. An interesting aspect of the multiple read-out model is that more than one code can be generated and the "correct" code might depend on the task itself (Grainger & Jacobs, 1996). Basically, this means that a code can be generated that is not correct, but based on the task it is close enough to generate a response.

Figure 1 presents a Venn diagram as graphic representation of functional overlap between modalities from Grainger and Jacobs (1996). While this is not a specific representation of the multiple read-out model, it does represent the components of visual word recognition whereby "word recognition" requires specific unit activation, regardless of task, with an additional component of global activation from each specific methodology. This diagram also exhibits the overlap between tasks while recognizing that some aspects of each methodology stand alone.

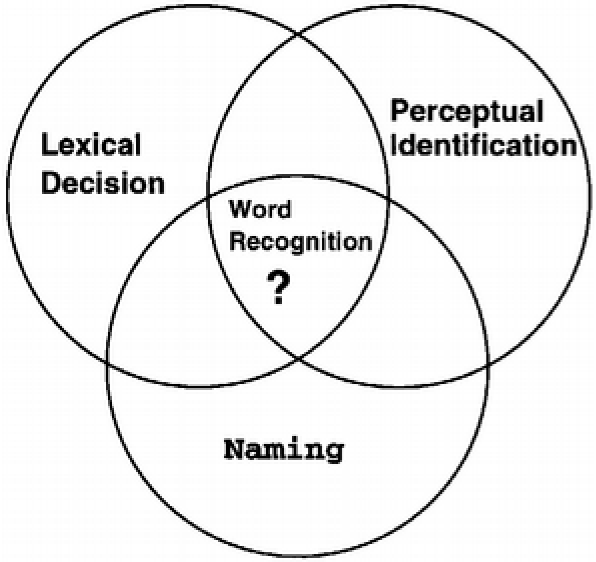


Figure 1: Image taken from Grainger & Jacobs (1996).

For example, presenting the letters “h” “a” “t” should activate a specific lexical representation of “hat” which would be the unit level. Globally, those same three letters should activate the entire orthographic neighborhood surrounding “hat.” If either the global level or the unit level reaches the activation threshold, then a participant can respond to that word.

Ferrand and Grainger (1996) took the multiple read-out model one step further. They used it to not only examine orthography but to also incorporate phonology, focusing on the possible dissociation between phonology and orthography in the presence of different types of foils in a lexical decision task. They examined homophones and pseudohomophones in the context of low-frequency words, orthographically legal nonwords, pseudohomophone nonwords, and illegal nonwords. Based on the type of foil, the orthographic effects ranged from being facilitative to inhibitory. This suggests that participants based their responses on global versus unit level activity as the task called for. Specifically, when pseudohomophones are used as the nonword foils, global activation can no longer be relied upon to generate an accurate response. Due to the overlap between the pseudohomophones and the activation of the word itself, too many false positives would be generated. In this case, a participant would be forced to rely on unit level activation. The model would predict inhibition for words with large neighborhoods when pseudohomophones are used as nonwords because of the competition involved in selecting appropriate unit level activation. The outcome from the Ferrand and Grainger's study (1996) is exactly what is predicted by the model (with only minimal adjustments to distinguish which code should be used to make a decision.)

Parallel Distributed Processing Model

Parallel distributed processing models (PDP) have been applied to orthographic neighborhood research. Seidenberg and McClelland (1989) used their PDP "triangle" model to simulate the effects of N. A PDP model is an approach whereby processing is defined in terms of layers of neuron-like programming units. The model described by Seidenberg and McClelland has both phonological and orthographic representations with weighted connections to a layer of hidden units. For a graphic representation of this model, see Figure 2. These weights start at, and are modified by, a set of parameters (learning rules). A word is represented as a pattern of activation across the network, as partly determined by the hidden layer. By training the model, the weights of the connection are changed to give the correct output.

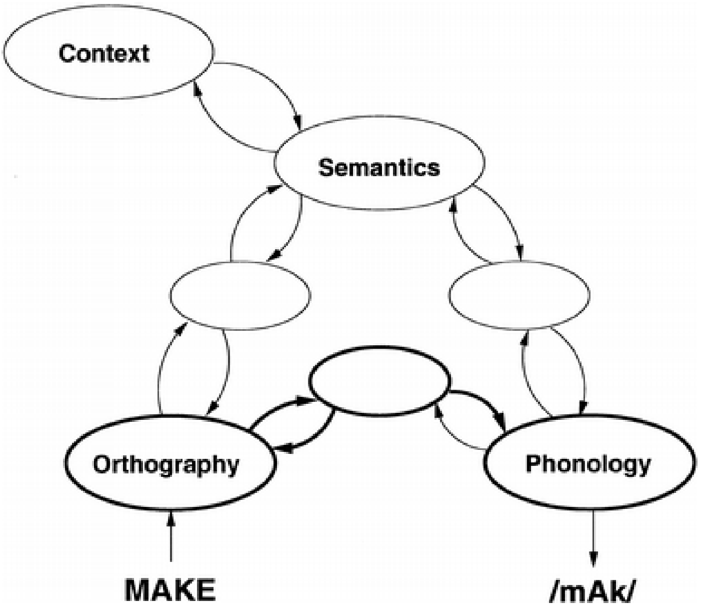


Figure 2: Image taken from Harm & Seidenberg (2004)

Seidenberg and McClelland (1989) predicted that N would be facilitative because the weights are increased by each presentation of a word. Orthographic neighbors are very similar to the target word and activate some of the same nodes, setting the weights closer to a correct output. Higher error scores are associated with slower response times, and lower error scores equal a faster response. Having more neighbors is similar to more presentations of the target, leading to more adjustment of the weights, which would lead to a facilitative effect. This is what Seidenberg and McClelland found in their simulation. Based on similar words, as well as target words, adjusting weights in favor of the correct response, words with more neighbors should be processed more quickly because those weights would be set higher. Further, this would be stronger for low-frequency words because high-frequency words would reach some ceiling whereby neighbors would be able to provide little extra aid. This PDP model was successful in simulating this neighborhood effect as well as other phenomena in visual word recognition (Seidenberg & McClelland, 1989).

Seidenberg and McClelland (1989) presented their PDP "triangle" model with the intention to study the interaction between orthography and phonology. Harm and Seidenberg (2004) presented a revised model with the intention of examining the role of generating semantic codes from both orthography and an orthographic-phonologically mediated pathway. In other words, they examined whether there is a direct mapping between orthography to semantics, or whether words are visually presented and then meaning is derived through phonological mediation. Figure 3 is a graphic representation of the levels and connections between levels for this model (Harm & Seidenberg, 2004). Their simulations replicated the behavioral findings to indicate that both processes are used and can be task and/or stimuli dependent.

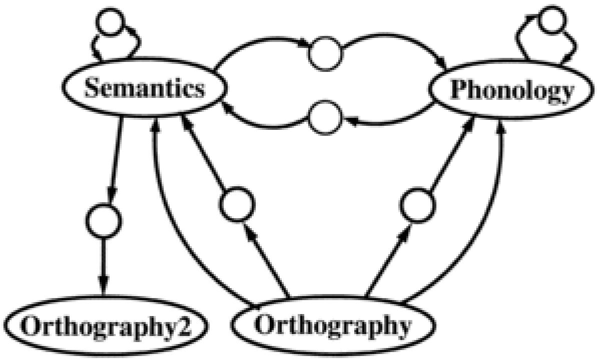


Figure 3: Image 2 taken from Harm & Seidenberg (2004).

In terms of orthography, it is difficult to say exactly what PDP models in general would predict, for several reasons. First of all, PDP models can have either inhibitory or excitatory connections. Secondly, even a specific PDP model, like the one by Seidenberg and McClelland (1989), can be trained with a different set of parameters. It is even possible that one set of parameters could be used to explain orthographic effects and a different set of parameters (on the same model) could be used to explain something like a frequency effect. In short, there are many classes of PDP models. Further, Harm and Seidenberg (2004) admit than neither form of the “triangle” model has been used to address strictly orthographic components.

This begs the question, is it the same model if the same set of parameters cannot account for different data? More specifically, Andrews (1997) directly questions the ability of the Seidenberg and McClelland (1989) model to account for facilitative N effects. Andrews points out that there was a single training set that was not fully interactive in terms of using orthography, phonology, and meaning (as the model is designed). Plaut, McClelland, Seidenberg, and Patterson (1996) have implemented a PDP model that would allow a test between error scores and a stochastic simulation; however, the effects of N have not been investigated with this model (as cited in Andrews, 1997).

Dual Route Cascaded Model

The third type of model that has been used to test the effects of orthographic neighborhoods is the dual route cascaded (DRC) model developed by Coltheart et al. (2001). The DRC model is a computational model that consists of a general rule route (which processes words through a set of grapheme-phoneme conversion – GPC – rules), a lexical route (where lexical entries are defined by their orthographic makeup), and a mediated semantic-lexical route.

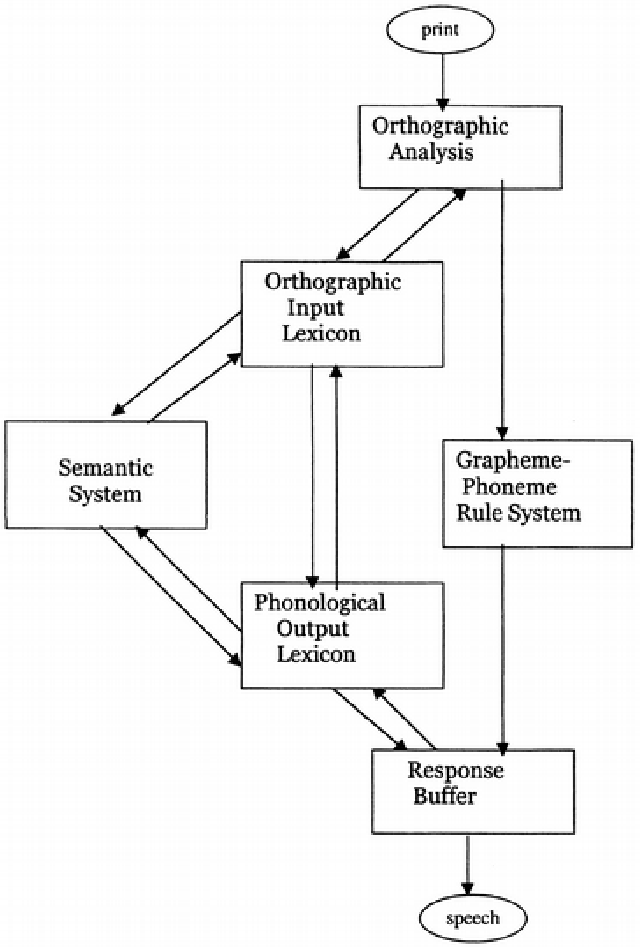


*Figure 4: Taken from Coltheart et al., (2001).

There is parallel processing throughout both (phonological and orthographic) lexicons in the DRC model. This processing makes use of both excitatory and inhibitory connections. The process that the DRC model goes through to generate a pronunciation is as follows: A word's letter features activate the word's letter units. This letter activation leads to activation of the corresponding entry in the orthographic lexicon. This entry activates the corresponding phonological entry which activates the phonemes that begin the speech process. The entire activation process occurs in parallel across phoneme and letter positions (Coltheart et al., 2001).

The DRC model is not, however, fully parallel. The GPC route (the rule route) incorporates only serial processing and has only excitatory connections. To generate a pronunciation based on the rule route the letter features are activated. The first letter of input is passed through a set of rules and a rule can be matched to the letter to generate the appropriate phoneme. Then that phoneme's unit receives activation. This process continues one letter at a time until the full word has been processed and the correct phoneme units have been activated (Coltheart et. al., 2001).

The DRC model makes a specific prediction in regards to reading aloud. Words and nonwords with many neighbors should both be read aloud faster than words or nonwords with fewer neighbors (Coltheart et al., 2001). Specifically, the cascaded processing allows orthographically similar words to be activated and that activation feeds down to the phoneme level. This is like the global activation found in the model presented by Grainger & Jacobs (1996). However, this is not what they found. Coltheart et al.'s simulation found no neighborhood effects in naming latencies with the DRC model. It is important to point out that this is different from what is found with normal readers.

The results from the DRC model concerning lexical decision were similar to those in reading aloud. The prediction here is that words from large orthographic neighborhoods would be inhibitory unless the target word in question was the highest frequency word from its neighborhood. However, the model's behavior did not match human data. Consequently, Coltheart et al. (2001) included the proposition of the “fast guess criterion” developed by Grainger and Jacobs (1996). The “fast guess criterion” consists of two ways to respond YES that an item is a word and one way to decide NO. To decide YES, either the single specific lexical entry needs to be selected or a total global activation of the orthographic lexicon must meet some specific activation level (although this level is not specified). A NO decision is made if no lexical entry is found (Coltheart et al.). Basically, to replicate human data both the DRC model and the IA model rely on different procedures for lexical decision and reading aloud. This statement is not meant as a criticism of the models. It is, rather, a point for future consideration as a possible explanation for seemingly conflicting results about the role of orthographic neighborhood effects in visual word recognition.

Each of the models presented here (interactive activation, PDP, and DRC models) seems very capable of accounting for N effects, but it is important to note that they are different models. No model presented here can be discounted on its ability (or inability) to account for an effect. However, as has been pointed out, each of these models has at least some problem directly related to the effects of orthographic neighborhood. Further, if there are conflicting results with the same task, no single model can account for all results. With both the PDP and the DRC models relying on parameters that can be easily changed to match human data, this is a legitimate concern. Should a model have a single parameter set that must account for all effects seen in human data or is it sufficient that a model account for human data with any parameter set? The following section discusses aspects of orthographic neighborhoods for which a model would need to account.

Orthographic Neighborhoods

In the last several years much work has been done on the role of orthographic neighbors in visual word recognition. Research evidence appears to be contradictory with some studies finding facilitative effects for words with large orthographic neighborhood size and others finding inhibitory effects (Andrews, 1997). However, Andrews' comprehensive review did little to end the debate about the role of N (see Mathey, 2001; and Perea & Rosa, 2000) despite the declaration that the conflict in evidence appears more problematic than it is (Andrews, 1997.) Although these studies are approaching a decade in age, they are still frequently cited and are used as prominent guides as to the role of orthographic neighborhood effects (see Adelman & Brown, 2007: Sears, Campbell, & Lupker, 2006). The question still seems to be, what role does N play in visual word recognition?

There are three possibilities concerning the role of N: N has a facilitative effect, an inhibitory effect, or there is no effect of N in visual word recognition. The controversy of N lies in the fact that all three of these results have been found in various studies at various times. Further complicating the matter is how a researcher measures visual word recognition. Among the possibilities are the lexical decision task, naming, and perceptual identification.

Andrews' (1997) reviewed 26 studies examining orthographic neighborhood effects reported between 1977 and 1997. Of these 26 studies, four found mixed results, ten found facilitative effects, one found inhibitory effects, and another 11 found either null effects or did not examine N. Even though she indicated that the controversy about whether or not orthographic neighborhood density is facilitative or inhibitory is not real, it seems clear from her review that this is not the case. Andrews argues that the reason for the different results is because of task effects. Even though there appear to be different results based on different tasks, the inconsistent results are actually based on variables outside of the realm of orthographic neighborhoods (Andrews, 1997). For example, Andrews points to a perceptual identification experiment in which Snodgrass and Minzer (1993) attribute inhibitory findings to a response-bias effect. Across five experiments studying perceptual identification, Snodgrass and Minzer only found an inhibitory effect for low-frequency words from large neighborhoods in a single identification paradigm (the participants were only allowed to make one guess). When participants were allowed to make successive guesses, no effects of neighborhood density were found. Based on these, they conclude that participants usually guess the highest frequency neighbor because there is no reason not to (as cited by Andrews, 1997).

Here it is also important to point out that some consider the lexical decision task to also be subject to guessing strategies. This would be the equivalent of choosing to use global activation over unit level activation in Grainger and Jacobs (1996) multiple read-out model. In a lexical decision task, global activation leads to facilitation because it is not necessary to come up with the exact lexical match as long as a certain level of activation is obtained. When unit level activation is necessary, MROM predicts inhibition because all the lexical items selected in global activation must be excluded to obtain the exact lexical match. This implies that there are different metrics (global and unit activation) to measure orthographic neighborhood size.

Andrews discussed the differential effects of N across tasks, including perceptual identification (identifying a word that has been degraded in some manner), lexical decision (identifying a letter string as either a word or not a word), naming (saying or reading a word), and semantic decision (identifying semantic categories or connections). Within these different experimental contexts, naming and LDT exhibit mostly facilitative effects with only one experiment showing results that indicated inhibition (see Johnson & Pugh, 1994), and two experiments showing mixed effects that included null effects and facilitation (see Carreiras, Perea, & Grainger , 1997; Grainger & Jacobs, 1996).

Several studies suggest that task-specific effects may underlie the contradictory evidence in N results (see Andrews, 1997; Huntsman & Lima, 2002; Perea & Rosa, 2000). Coltheart et al. (2001) presented the DRC model with the specific intention of accounting for both reading and lexical decision tasks. In fact, they do predict different results for the role of orthographic neighborhoods in the two tasks. The model theoretically predicts that N will be facilitative in reading even though their simulations do not exhibit this. The simulations may not exhibit these results due to two possibilities: Either the model is wrong about its prediction or the simulations of the model are not sophisticated enough to replicate human readers.

Coltheart et al. conclude that the model partially fails because it cannot replicate human readers; however, their results are more similar to those found by Pollatsek et al. (1999) than to those of Andrews (1997). The model could still be either wrong or the simulations could have been inferior to real readers in some way. The only clear result is that more testing needs to be done.

Further, the DRC model would predict an inhibitory effect of (large) neighborhood size in lexical decision unless the target word is the highest frequency word from that neighborhood (Coltheart et al., 2001). However, this prediction is discounted in favor of the predictions of Jacobs and Grainger’s (1996) IA model. In this model, Jacobs and Grainger make the distinction of global activation of a word, which is used for lexical decision tasks, and unit activation of words, which is used for reading aloud. Here, a lexical decision can be made when the neighborhood of a word is activated and not necessarily when the word is activated. However, in reading aloud the exact units of the word must be activated before the correct lexical choice can be made and read. Two separate models acknowledge the very thing that Andrews (1997) and Pollatsek et al. (1999) seem to be dismissing (i.e. facilitation in lexical decision and inhibition in reading for large orthographic neighborhoods).

Andrews (1997) advocates concentration on the findings based on naming and LDT, citing evidence that the primarily inhibitory results stemming from the perceptual identification task possibly reflect a guessing strategy (i.e. guessing the highest frequency neighbor). Huntsman and Lima (2002) agreed that it is likely that the perceptual identification task is possibly subject to guessing strategies; however, they also admit that LDT might involve something other than lexical access (like a general level of global activation that would require a level of activation to be met without a specific lexical item being selected).

Perea (1998) used the “three-field technique” and demonstrated an inhibitory effect of orthographic neighborhood size. In this procedure a visible prime is followed by a brief target word that is then masked. Subjects are then asked to write down the masked word and press the space bar to move on. For primes and targets that differed at the third or fourth letter, there was a significant inhibitory effect (increased errors) of a large N (Perea, 1998). It is possible to argue that this outcome might be specific to this task. This could be attributed to a serial position effect (better recall for the first and last items presented and poor memory for the items presented in the middle). However, subjects could also have more interference when inner letters of the target differ because they are confused about the possibility that they might have missed beginning letters.

Carreiras et al. (1997) conducted a study that investigated five tasks: progressive de-masking (a stimulus is presented very quickly and then masked; this procedure repeats multiple times for the same stimulus, with each presentation getting longer and each mask getting shorter for a specific amount of time—like 500 msec—or until the participant can identify the word), blocked lexical decision (words from large neighborhoods were presented in a single experimental block and words from small neighborhoods were presented in another experimental block), naming, semantic categorization, and standard LDT. They manipulated both N. For FN, they found inhibitory effects in progressive de-masking and both LD tasks. The results for naming and the semantic categorization task yielded mixed results mediated by N (meaning that there was an interaction between N and FN). For N, there were significant facilitative effects for blocked LDT and for naming (mediated by the presence of higher frequency neighbors). These results seem to coincide with the conclusions of Andrews (1997) that N appears to show facilitation whereas FN tends to show inhibition.

This conclusion does not mean that any specific method is the best way to assess the role of N (at this time). The differential results between reading and LDT found by Pollatsek et al. (1999) and Carreiras et al. (1997) seem to indicate that different tasks change the response criteria. LDT and reading tasks might be tapping into the lexicon in different ways. Until these discrepancies can be resolved, it will be difficult to interpret the pattern of results obtained in the literature.

The Interaction Between Orthographic and Phonological Neighborhoods

The Reimer et al. (2008) study included not only a look at prime/target pairings but also phonology. Yates, Locker, and Simpson (2004) demonstrated that phonological neighborhood plays a significant role in visual word recognition. In a series of two LDT experiments that controlled for a variety of lexical characteristics, they found that phonological neighborhoods are facilitative in visual word recognition. This means that the spelling of a word is not the only information affecting lexical access of visual information. Since this is the case, it is important to explore how orthography and phonology interact with one another.

Through a series of five experiments, Peereman and Content (1997) demonstrated that combined orthographic and phonologic overlap is necessary to demonstrate facilitative effects for French words in a naming task. Their series of experiments explored both varying numbers of neighbors and position of feature change in a word. The procedure consisted of presenting pseudowords with many true orthographic neighbors, like *vorte*—which has seven orthographic neighbors (that are French words). Of these seven neighbors, six are also phonological neighbors. The second set of pseudowords, like *oure*, had 10 orthographic neighbors of which only one was an actual phonological neighbor. Only pseudowords with both large orthographic and phonologic neighborhoods showed facilitation. Neighborhood effects are only facilitative if both orthographic and phonologic neighborhoods are large, at least in naming.

Adelman and Brown (2007) took the overlap between orthography and phonology one step further. They used the term phonographic neighbors to directly describe the situation in which orthography and phonology are more than covariates. Adelman and Brown define a phonographic neighbor as a word that is both a phonological and an orthographic neighbor. The example they use is “stove.” “Shove” and “stone” are both orthographic neighbors, but “stone” is also a phonological neighbor. “Stove” and “stone” would be phonographic neighbors but “shove” would not.

Adelman and Brown (2007) utilized a regression analysis to examine the naming latencies from four mega-studies (Spieler & Balota, 1997; Balota & Spieler, 1998; Seidenberg & Waters, 1989; and Balota et al., 2000; as cited by Adelman and Brown, 2007). By categorizing words as orthographic and/or phonographic neighbors, they concluded that having a large phonographic neighborhood was facilitatory across all four studies. In three of the mega-studies, however, no effect of orthographic neighborhood was found. In the fourth study (from the Seidenberg and Waters, 1989 norms) evidence for an inhibitory effect of orthographic neighborhood size was found. Adelman and Brown concluded that the orthographic neighborhood effects seen in previous studies could be attributed to the overlap between phonology and orthography and not from purely orthographic processing.

A case study reported by Lavidor, Johnston, and Snowling (2006) also sheds some light on the interplay between orthography and phonology. They examined a subject (FM), a group of adults with dyslexia, and a group of normal readers in a divided visual field paradigm. FM had been diagnosed with developmental dyslexia at age 8. This type of dyslexia is marked by a deficient usage of phonological encoding. In the case of FM, there was an inhibitory effect of orthographic neighborhood size (N) in the right visual field. Lavidor et al. also explored a group of age-matched controls and a group of dyslexics similar to FM. The inhibitory effect was also exhibited by the group with dyslexia--even though the effect was not as strong. No effect of orthography was found with the controls. Lavidor et al. argue that FM and the dyslexic individuals are more sensitive to orthographic cues because the phonological system is not intact. This is what differentiates FM and developmental dyslexic individuals from “normal” readers. The findings indicate that there is some kind of normal interaction between phonology and orthography that is not there for individuals like FM. This lack of interaction caused an inhibitory effect not seen in control subjects (Lavidor et al.).

It is important to note that this is not the only type or definition of dyslexia; however, it is the one used and defined as such by the authors. Other types of dyslexia might lead to a different result. For example, individuals with surface dyslexia have no problems with phonological processes. They can read regular words and regular non-words quite well. However, these individuals have problems with irregular orthographic-to-phonological mappings. In other words, they read irregular words as if they were regular. For example, someone with surface dyslexia might read “pint” to rhyme with “mint”. These individuals might be more sensitive to phonological cues than the individuals in the study from Lavidor et al. (2006). In this case, one would not predict an inhibitory effect of orthography.

Semantic Constraints on Orthographic Neighborhood Size

Pollatsek et al. (1999) demonstrated that a large N is facilitative in LDT and inhibitory in reading. This outcome led Perea and Rosa (2000) to conclude that a lexical decision task is not an appropriate tool to study orthographic neighborhood. Perea and Rosa explain that ultimately the purpose of studying lexical access is to understand reading, and that, because reading and LDT give different results (see Pollatsek et al., 1999), LDT should not be used.

Again, exploring the models related to visual word perception is very useful. The IA multiple read-out model presented by Grainger and Jacobs (1996) (also see

Ferrand & Grainger, 1996) describes word-level as well as global activation. They argued that global activation allows for not only the lexical item being studied to be activated but also neighbors as well. The more neighbors a word possesses the faster it is processed, and facilitation is found in lexical decision. However, reading aloud or silently (or eye tracking) requires the full word-specific level to be activated. Here, there is competition among words from the same neighborhoods. Therefore, large neighborhoods should be inhibitory (see Ferrand & Grainger, 1996; Grainger & Jacobs, 1996).

The DRC model presented by Coltheart et al. (2001) would make similar predictions. Facilitation from large orthographic neighborhoods in lexical decision will be accounted for using the "three criterion account" previously discussed by Grainger and Jacobs (1996). Namely, this would mean that lexical decisions are based on activation of the entire neighborhood and not just the exact lexical representation of the word being processed. In reading, however, both the GPC rule route and the lexicon are responsible for activating and selecting the exact lexical entry. This means that the word is processed letter-by-letter in a serial fashion while it is being looked up in parallel in the mental lexicon (Coltheart et al., 2001). Once the exact entry is specified, the pronunciation is generated.

It is easy to see how the DRC could account for Pollatsek et al.'s (1999) results. If neighborhood size is facilitative on global activation and word level activation is inhibitory, then we should see a reversal of results for LDT (facilitation) and eye tracking (inhibition). Further, if a process requires information from both the word level and global level of activation, it is clear that we could expect to see early versus late processing differences. In eye tracking, first pass reading might rely on global activation and large neighborhoods would be facilitative. Later occurring regressive eye movements might be initiated by the word level information and show inhibition for larger neighborhoods. Since full comprehension requires full lexical access, the overall reliance on word-level information should cause an overall inhibitory effect of neighborhood size or a null effect if it is counteracted by the facilitative effect of global activation. This is what Pollatsek et al. predicted and found in Experiment 3 (however they were manipulating the number of low frequency neighbors). Again, the cross-task (eye tracking versus lexical decision) comparison here is problematic as eye tracking can allow for regressions to previously presented words (i.e. activating the same target multiple times) but lexical decisions do not. A lexical decision task does not typically provide context, except in the case of priming.

Adelman and Brown (2007) used a regression analysis to examine naming latencies from four mega-studies and concluded that there was no effect of orthographic neighborhood in three of the studies. In the fourth study (based on the Seidenberg and Waters, 1989 norms) evidence for an inhibitory effect of orthographic neighborhood size was found. This is in contrast to the conclusions by Andrews (1987), who claimed that orthographic neighborhood size is facilitative in both LD and naming. However, of the studies included in her review, not all naming studies exhibited a facilitative effect. Even models of visual word recognition disagree as to the role of orthographic neighborhood size in naming and LD.

A naming task requires specific lexical retrieval of a word to activate the correct phonological representation. Based on this, one would expect to see large neighborhoods as inhibitory in a naming task because of the reliance on word-level activation and not global activation (see Grainger & Jacobs, 1996). The DRC model (Coltheart et al., 2001) bases its prediction on the "fast guess" strategy that is very much like what Grainger and Jacobs suggest for their model. Therefore, large neighborhoods should be inhibitory in naming. These predictions are in sharp contrast to the facilitative effects these models predict for a lexical decision task. The "triangle" model (Harm & Seidenberg, 2004: Seidenberg & McClelland, 1989) predicts that larger neighborhood sizes increase the connection weights in favor of a faster and more accurate response. In both a reading and a lexical decision task, the "triangle" model would predict facilitation for large neighborhood sizes (orthographic and phonologic).

Pollatsek et al.'s (1999) found an early facilitative effect of large orthographic neighborhoods. However, they also found that these early effects were linked with the target word being skipped more often. Skipping caused a late inhibitory effect of the number of higher-frequency neighbors. They proposed that the inhibitory effect occurred because of misidentification of the target word for one of its higher-frequency neighbors in the original fixation. Once that misidentification was discovered, because the sentence did not make sense, the participant was forced to go back and reread the target word, thus causing slower overall processing (Pollatsek et al.). It has been hypothesized that N is partially facilitative because of general levels of activation of the neighborhood as a whole and not actual lexical access for the correct target word (see Perea & Rosa, 2000).

The naming task prevents this misidentification problem. A participant must understand the word and have full lexical access before responding. Basically, by embedding target words varied on N, phonology, or any combination of variables in a priming based naming task, we can compare the results to those found in both LDT and in eye-tracking data.

This is the basic argument motivating the research of Reimer et al. (2008). They employed a priming paradigm to study the influence of orthography, phonology, and semantics, specifically, to determine how semantics influence phonological and/or orthographic processes. A mediated priming task was used where target items were either homophonically (phonological condition) mediated, as in “frog” priming “towed,” which is phonologically similar to the prime’s semantically related word “toad;” orthographically mediated, where a sample prime would be “frog” and the target would be “told” which is orthographically similar to the prime’s semantically related word “toad;” or the items were associatively related as in “frog” and “toad.” In naming, they found a significant facilitative priming effect for orthographically mediated words but not for homophonically (phonology) mediated words. Similarly, Locker, Simpson, and Yates (2003) found that orthographic and phonological processing is facilitated for words that are better represented at the semantic level.

Hino, Pexman, and Lupker (2006) point out that PDP models, specifically, predict that processing speed of the semantic code relies on the relationship between orthography and semantics. For example, ambiguous words have a processing advantage because there is more information modulated in the orthographic-to-semantic mappings (Kellas, Ferraro, & Simpson, 1988). In other words, to the extent that a word has more meanings (and the more related those meanings are to one another), there is more information to map onto between the orthographic representation and semantics. This leads to a facilitative effect of ambiguous words.

Seemingly, when semantic information is activated it places a reliance on unit level as opposed to global activation. Global activation is typically linked to facilitation in lexical decision tasks and the lack of facilitative effects are attributed to unit level activation in the naming task (see Ferrand & Grainger, 1996; Grainger & Jacobs, 1996). However, Reimer et al. (2008) were able to find facilitation for orthographically mediated primes in naming. This result goes against the idea that naming typically relies on unit level activation which does not elicit facilitative effects. Also, this argument lends value to the idea that even if semantic access in priming causes reliance on unit level activation that unit level activation must predict a non-facilitative effect.

Reimer et al. (2008) also found a facilitative effect of semantically related orthographically mediated primes at both 53 and 413 ms prime exposure points. The facilitative effect did not occur for homophonically mediated primes at either SOA. Reimer et al. interpreted this to mean that at both long and short prime durations, semantic information feeds back to the orthographic units, speeding processing. Semantic information, however, does not feed back to the phonological level as the phonological processing is not affected by prime processing time. The Reimer et al. study was designed to examine the automaticity of priming (early processing is automatic and later processing is strategic). However, this study does little to show the time course of lexical activation. It is possible that phonological processing is aided (automatically or not) by semantic associates, but at a longer SOA than the one used by Reimer et al. By holding the prime duration constant (50 ms) and manipulating SOA, perhaps we might find that orthographically mediated primes are facilitative at short SOAs but not long SOAs, and phonologically mediated primes are facilitative at long SOAs but not at short SOAs, all of which might be automatic or not.

By incorporating a semantically related prime in a lexical decision task, we can examine the time course of activation, and we can compare global and unit level activation in the same task. When a semantically related prime is present, global activation can no longer be relied upon because semantic information is typically processed later in lexical retrieval (word-level activation) than orthographic information alone (global activation). Targets paired with semantically related primes may use unit level activation to narrow activation to a single unit, so neighborhood size effects are diminished.

CHAPTER II

EXPERIMENT 1

Within this paper, and elsewhere, there has been much discussion about the potential effects of orthographic neighborhoods. The problem with most of the conclusions surrounding orthographic neighborhoods is that these have been mostly studied in isolation, with controls on phonological neighborhood, semantic neighborhoods, frequency, log frequency, etc. In essence, every characteristic known to influence lexical access is controlled for. This approach isolates the orthographic neighborhood effect but tells us little about how neighborhood characteristics might be influencing lexical access in everyday terms.

Before the effects of N can be understood N must be studied in the context of other variables. Andrews (1997) pointed out that due to the complexity of lexical components that make up words there is always potential for different results for different words. Andrews went on to state that a priming experiment might be an effective way to resolve this problem because this type of experiment would allow for the words to serve as their own controls, thereby, eliminating potential covariates. Priming also has the advantage of addressing neighborhoods in the context of word meaning. In other words, priming is an excellent way to look at how multiple components of visual word recognition interact.

A priming experiment would provide an opportunity to study phonology, semantics, and orthography together. Since both orthographic and phonological neighborhood size impact words at the lexical level, a priming experiment enables the experimenter to examine lexical and semantic components at the same time.

Reimer et al. (2008) employed a priming paradigm to study the influence of semantics in naming. They examined the relations among orthography, phonology, and semantics in a mediated priming task. They found that once semantic information is activated it feeds back to the orthographic level causing a facilitative orthographic mediated priming effect but there was no comparable effect for homophonically mediated primes.

Reimer et al. (2008) claim that the purpose of semantic feedback is to facilitate orthographic processing because, ultimately, the goal of semantic and phonologic integration is to aid orthographic processing as it is paramount in visual word recognition. Whether or not orthography is the dominant focus of the visual word recognition system, all three models (the multiple read-out model, the triangle model, and the dual route cascaded model) presented in this paper have included semantic, orthographic, and phonological representations.

For example, Ferrand and Grainger (1996) proposed a multiple read-out model (MROM) that relies partly on the interaction of activation from the phonological system with the orthographic system as well as a summed global activation. There are two lexicons that are activated for a given letter string presentation. One is a phonological lexicon and the other is an orthographic lexicon. When a word is presented that activates both systems, there is maximum competition between orthographic and phonological word activations that leads to inhibition (i.e.

inhibition occurs when words are primed with orthographically related pseudohomophones).

MROM would predict that words with both large orthographic and phonological neighborhoods should show inhibition because reliance on global activation would create too many errors. If specific lexical representations are necessary (e.g., in a naming task) then the reliance on the specific lexical entry should cause inhibition in larger neighborhoods (either phonology or orthography). All nonwords would require unit level activation because they have not been categorized as a part of the lexicon where global activation occurs. Facilitation would only occur if a participant can rely on global activation.

The results from Reimer et al. (2008) would seem to contradict these predictions, however. They found a facilitative effect for semantic information feeding back to the orthographic level. Seemingly, this would mean that the addition of semantic information aids in orthographic processing. Ferrand and Grainger (1996) and Grainger & Jacobs (1996) both predict that facilitation is found in lexical decision and not naming because LD allows participants to rely on global activation where the specific lexical entry has not been selected. Reimer et al. are arguing that semantic information is available and feeds back to the orthographic level and this feedback facilitates processing. If semantic information is available, according to Ferrand and Grainger (1996) and Grainger & Jacobs (1996) then unit level information is being used. They argue that the reliance on global activation instead of unit level activation is why a facilitative orthographic neighborhood effect is found in lexical decision and not in naming. Reimer et al.'s results indicate that there should not be a difference in naming and lexical decision tasks, and orthographic information should facilitate processing especially in the context of semantics.

This is very much like the DRC model presented by Coltheart et al. (2001). The DRC model has two distinct pathways: orthographic/phonologic lexicon that can be mediated by semantics, and a GPC-rule system. Although Coltheart et al. make no predictions regarding the semantic system, the three systems are linked, and needed, for processing in visual word recognition. Coltheart et al.'s graphic representation of the DRC model shows how the system should work. In particular, the semantic system has both a feed-forward and a feedback connection to both the orthographic input lexicon and the phonological output lexicon. As orthographic information arrives and is activated in the orthographic lexicon the information passes to the semantic system. Once the information arrives in the semantic system, processing begins that feeds back to the orthographic lexicon and feeds forward to the phonological output lexicon. The phonological output lexicon is then capable of feeding this information back to the semantic system as well as straight to the orthographic lexicon (Coltheart et al, 2001).

The DRC model predicts neighborhood facilitation in both lexical decision and naming. This facilitation relies on a combination of orthography, phonology, and semantics. All three systems are interactive and capable of direct communication with each other. Unfortunately, simulations of the model do not match the bulk of human data. Specifically, no orthographic facilitation was found (Coltheart et al., 2001), and the only way for the model to account for orthographic facilitation in lexical decision was to rely on the assumptions of global activation made in Grainger and Jacob's (1996) model. Basing the DRC model on the assumptions of the model by Grainger and Jacob, the DRC would then predict facilitation of large orthographic neighborhood size in lexical decision tasks but inhibition would be found for those same words in a reading (or naming) task.

It would be helpful if the semantic system were more precisely defined by Coltheart et al. (2001). Does the semantic system represent a semantic lexicon where neighborhood representation is incorporated? If so, related semantic associates should be facilitative. This distinction is necessary to make accurate model predictions. When deciding if data match model predictions, the components that the predictions are based on must be explicit. Without them, one cannot decide if the model needs revision or if a component needs to be more precisely defined when the data do not match the prediction. However, the DRC model firmly incorporates semantics, phonology, and orthography, and future experiments should, as well.

When any given system is activated in processing, it is quite possible that residual activation from another system would be problematic. For example, when producing the correct phonology is important, words activated that look the same but sound different (orthographic neighbors) would be problematic in choosing the correct pronunciation code. At this point, orthographic neighborhood size might be inhibitory.

Experiment 1--Priming

The current research examined phonology, orthography, and semantics in a priming context. Despite the findings concerning facilitative effects of large orthographic neighborhoods, there is still the question about whether these effects are a result of a phonological effect instead of an orthographic effect (see Williams, Perea, Pollatsek, & Rayner, 2006). Rather than holding one or the other constant, it seems important to manipulate them both (orthographic and phonological neighborhood size) in the context of semantics. Importantly, Reimer et al. (2008) found that feedback from semantics facilitates orthographic but not phonological processing in naming. The same three components should be examined in a lexical decision paradigm in order to provide converging evidence, as well as to assess the possibility of task dependency. This is especially important as Yates et al. (2004) have demonstrated a facilitative effect of phonological neighborhood size in visual word perception.

Schiller (2007) concluded that there was enough evidence from past studies to conclude that orthographic information plays an early role in processing and that phonology plays a later role in processing. This would mean there should be a facilitative effect of orthographic neighborhoods at a short SOA but little or no effects at longer SOAs. Conversely, there should be little or no facilitation of phonological neighborhood at a short SOA. At a medium or long SOA, however, we might expect to find facilitation for phonological neighborhood size. The semantic component should be processed somewhere between the orthographic and the phonologic system (as it is in the DRC model from Coltheart et al., 2001). Consequently, facilitation (or inhibition) for related semantic associates should occur after the orthographic effects and before the phonological effects, although it has been found that priming shows up very early.

Such a pattern of results was reported by Reimer et al. (2008). They found a facilitative effect of semantically related orthographically mediated primes at both 53 and 413 ms prime exposure points. The facilitative effect did not occur for homophonically (phonologically) mediated primes at either SOA. Reimer et al. interpreted this to mean that at both long and short prime durations semantic information feeds back to the orthographic units speeding processing. Semantic information, however, does not feed back to the phonological level, regardless of prime processing time. The Reimer et al. study was designed to examine the automaticity of priming (early processing is automatic and later processing is strategic); however, this study does little to show the time course of lexical activation. It is possible that phonological processing is aided (automatically or not) by semantic associates but at a longer SOA than the one used by Reimer et al. By holding the prime duration constant (50 ms) and manipulating the SOA, perhaps we might find that orthographically mediated primes are facilitative at short SOAs but not long SOAs, and phonologically mediated primes are facilitative at long SOAs but not at short SOAs.

Grainger, Kiyonaga, and Holcomb (2006) used event-related potentials (ERPs) to examine the time course for orthographic and phonological priming with transposed-letter primes (two letters are switched). Their results showed an orthographic neighborhood effect 50 ms earlier than a phonological neighborhood effect. Both manipulations affected the N250 (which reflects sublexcial processing) and the N400 (which reflects semantics) ERP components which suggests effect boundaries around those time periods.

Further, Perea and Rosa (2000) argue that a reading paradigm (specifically, eye-track gaze duration) is better than LDT because it allows for conclusions about late versus early processing. By using eye tracking measures evidence can be taken from first-pass reading (early processing) and regressions (later processing). In fact, research by Pollatsek et al. (1999) demonstrated the importance of time course by finding a facilitative effect for more low-frequency neighbors early in processing (first fixation) but not at later points.

By employing a priming context, a lexical decision task may produce outcomes similar to eye-movement data. Priming allows for variable SOAs to study early versus late processing, and priming also allows us to incorporate semantics as in an eye movement study. Reimer et al. (2008) did just that in their investigation. They used priming to examine automaticity of semantic feedback and also demonstrated that semantic associations are used as an important component to orthographic access. One thing they did not do, was demonstrate whether phonology is important at later points in processing.

Method

Subjects

Participants were ninety-six English speakers (readers) selected from the University of Kansas General Psychology subject pool, or participating for extra credit in Psychological Statistics. All participants were asked to report whether they had normal or corrected-to-normal vision.

Stimuli

Every target was paired with a related prime. The prime-target pairs were orthogonally crossed based on the absence or presence of a semantically associated prime, the size of the orthographic neighborhood (large or small), and the size of the phonologically neighborhood (large or small). The unrelated primes were derived from the primes of other targets in the study that were not semantically related to the new target. This allowed for an examination of semantic relatedness, orthographic neighborhood size, and phonological neighborhood size.

Design and Procedure

This was a 2 x 2 x 2 x 3 design where orthographic neighborhood size, phonological neighborhood size, and semantic relatedness are compared across three SOAs (100, 300, and 500 ms).

Subjects were tested individually. They were first given an informed consent statement that briefly described the task they were to perform. Then they were seated in front of an Intel® Pentium 4 CPU running Microsoft Windows XP with a 17 inch monitor. The instructions were presented on the computer screen using an automated

E-Prime program (Schneider, Eschman, & Zuccolotto, 2002) designed to guide each participant through the entire experiment. Each participant was asked to respond as quickly and accurately as possible. The experiment was initiated by the participant by pressing any button on the keyboard.

Embedded within the E-Prime program (Schneider et al., 2002) was an SOA manipulation. Each participant saw prime/target pairings at all three SOAs (100, 300, and 500 ms) randomized throughout the list. Also, each prime/target pair was presented at all SOAs across subjects. Participants first received 15 practice trials that consisted of both the related and unrelated target/prime pairs as well as nonword foils as targets. Each participant received the same 15 practice trials. Once each participant completed the practice, he/she was given a break for questions and then asked to press any key on the keyboard to initiate the 92 trials.

Each participant first saw a fixation point marked by a + in the middle of the screen that lasted for 2000 ms. The prime was then presented for 50 ms. A mask consisting of 13 Xs (XXXXXXXXXXXXX) was placed over the exact spot where the prime was presented. The mask duration was dependent upon the SOA chosen. For the 100 ms SOA, the mask lasted for 50 ms. For the 300 ms SOA, the mask lasted for 250 ms; and the mask lasted for 450 ms at the 500 ms SOA. Then the target was presented. The participants were asked to press the “a” button if the target was not a word and the “l” button on the keyboard if it was a word. Accuracy and reaction time were collected from each participant.

Results and discussion

All analyses are based on the responses to the 92 experimental items of each list. Outliers were defined separately for each SOA. The mean and standard deviation for each of the three SOAs were calculated. If a response was faster than the mean minus two standard deviations or slower than the mean plus two standard deviations, the response was determined to be an outlier and was removed from the analysis. For the response time analysis, only correct responses were used. To fill in missing data, SPSS was used to perform a series mean transformation on the missing values. All analyses were performed on this transformed dataset. Given that the items used in this study were not random, tests on items as random variables were not conducted (see Reimer et al., 2008).

Using the reaction times as the dependent variable, a 2 (orthographic neighborhood size) x 2 (phonological neighborhood size) x 2 (relatedness) x 3 (SOA) repeated measures ANOVA was performed. All values are significant at $p < .05$ unless otherwise noted. The ANOVA on the reaction times showed a main effect of phonology, $F(1, 95) = 23.41$. Targets from a large phonological neighborhood were processed more quickly than targets from a small phonological neighborhood. There was also a significant main effect of priming, $F(1, 95) = 6.08$. Targets paired with a related prime were processed more quickly than targets paired with an unrelated prime (a mean difference of 9 ms). There was also a main effect of SOA, $F(2, 95) = 8.97$. A Bonferroni post hoc comparison indicated that targets processed at either a

300 or a 500 ms SOA were responded to more quickly than words presented with a 100 ms SOA (mean differences of 15 and 19, respectively).

The ANOVA also indicated several significant interactions. There was an interaction between orthography and SOA, F (2, 95) = 3.36. A follow-up ANOVA was conducted on the orthography by SOA interaction to analyze the simple effects. Only at the 500 ms SOA was there a facilitative effect of orthographic neighborhood size, whereby words from a large orthographic neighborhood were processed more quickly than those from a small orthographic neighborhood, F (1, 95) = 10.71, $p < .01$. This indicates that a participant gets the most benefit from a target being from a large orthographic neighborhood when he/she has a longer period of time to process that target.

There were also significant interactions between orthography and phonology, F (1, 95) = 21.22 and between phonology and relatedness, F (1, 95) = 7.85. These were qualified by a three-way interaction between orthography, phonology, and relatedness, F (1, 95) = 8.54. See Figure 4 for a graph of this interaction. The three-way interaction was further analyzed by examining the orthographic by phonological interaction separately for unrelated and related trials. The analysis performed on unrelated trials showed an interaction between orthographic and phonological neighborhood size, F (1, 95) = 34.5, $p < .01$. Simple effects tests showed that when the orthographic neighborhood was small, a large phonological neighborhood facilitated responding, relative to a small phonological neighborhood. There was no effect of phonological neighborhood size, however, when the orthographic neighborhood was large, F (1, 95) = .001. When targets followed related primes, the interaction of orthography and phonology was not significant, (F (1, 95) = 2.77, p = .1.

The orthographic main effect was F (1, 95) = 1.56. The remaining two way interactions of orthography by phonology (F (1, 95) = .002), relatedness by SOA (F (2, 94) = 2.18), and phonology by SOA (F (2, 94) = 1.6) were not significant. The remaining three-way interactions of orthography by phonology by SOA (F (2, 94) = 2.46) , orthography by relatedness by SOA (F (2, 94) = .5), and phonology by relatedness by SOA (F (2, 94) = 1.24) were also not significant. The four-way interaction of orthography by phonology by relatedness by SOA was also not significant, F (2, 94) = 1.07.

Using the accuracy as the dependent variable, a 2 (orthographic neighborhood size) x 2 (phonological neighborhood size) x 2 (relatedness) x 3 (SOA) repeated measures ANOVA was performed. All values are significant at p < .05 unless otherwise noted. The ANOVA on the accuracy showed a main effect of phonology, F (1, 95) = 5.704. Targets from a large phonological neighborhood were processed more accurately than targets from small phonological neighborhoods. There were no other significant main or interactive effects.

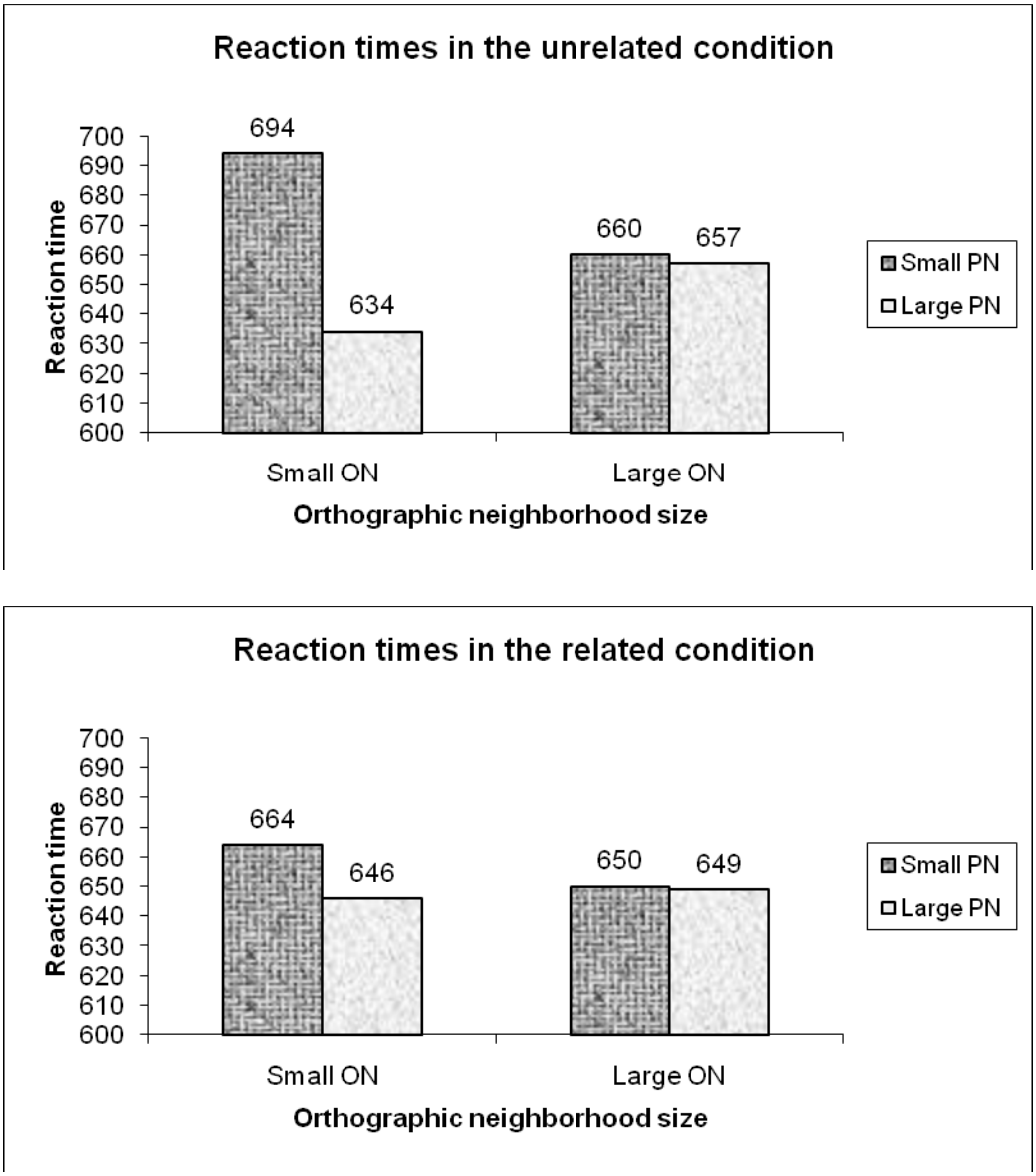


Figure 5: Three-way interaction between orthography, phonology, and relatedness

We would expect N to be facilitative (see Andrews, 1997), phonological neighborhoods to be facilitative (see Yates et al., 2004), and semantic relatedness to be facilitative in a lexical decision task. Phonological neighborhood size and having a semantically related prime are both facilitative to reaction times in lexical decision. Also, targets from a large phonological neighborhood are not only processed more quickly, but they are processed more accurately than those from a small phonological neighborhood. The models presented by Grainger and Jacob's (1996) and Coltheart et al., (2001) seem to be able to explain these main effects, as does the PDP model proposed by Harm and Seidenberg (2004).

The orthography by SOA interaction did not produce the expected results. Data from Schiller (2007) would predict that since orthographic access occurs early in processing, words processed at a short SOA should get as much benefit from orthographic information as words shown for longer SOAs. In fact, Locker et al. (2003) demonstrated early orthographic processing, as well. In this study, words from a large orthographic neighborhood are processed most quickly at the 500 ms SOA. This is contrary to the results of past experiments. In this study, it could simply be that we do not see early processing because these are words that get the most benefit from longer decision periods. In other words, these results may be task specific. In this study, three lexical variables are studied in relation to the time course of processing. It could be that when orthography is the only manipulated variable, we see very early facilitative effects. However, in the context of other lexical variables (phonology and semantics), the facilitative effect is not maximized until longer SOAs (i.e. the participant adopts a strategy to wait as long as possible for all information to come in).

A second possible explanation is the operational definition of what is early versus what is late in terms of processing. This study characterizes the combination of a 50 ms prime duration coupled with a 450 ISS as late processing. Reimer et al.

(2008) characterized and found significant priming for orthography at both a 53 ms and a 413 ms prime duration. Consequently, they also failed to find a significant effect of phonology on prime processing. Perhaps, 500 ms really is not late processing and this study does not go far enough in the SOA manipulation. To get a better grasp on the time course of orthographic processing, perhaps more than these three SOAs should be manipulated or the manipulation should consider longer SOAs (750 ms, for example).

The results indicated by the three-way interaction of Orthography, Phonology, and Relatedness are in keeping with some findings from previous research and are in stark contrast to others. Reimer et al. (2008) failed to find any feedback from semantics to phonology. However, there is an interaction between orthography, phonology, and priming that exhibits that processing is mediated by both orthography and phonology. Specifically, it is only in the unrelated condition that there is a demonstrated interaction between phonological and orthographic neighborhood size. In the presence of a semantically related prime, there is no interaction. Clearly, there is some processing between the semantic, phonological, and orthographic systems to negate the effect of neighborhood size found in the unrelated condition.

From the MROM and DRC perspectives, the LD task would rely on global activation which would elicit facilitative effects in the unrelated semantic associates' comparison. The addition of priming would provide semantic information that seems to feedback to the phonological system causing the reliance on unit level activation as opposed to global activation (a weaker facilitative phonological effect). When the orthographic and/or phonological neighborhood size is large the participant can rely on global activation which facilitates processing. The unrelated condition allows the participant to continue to use global activation and to rely on the facilitative effects the targets gets from being from a large phonological neighborhood. Participants are then faster in this unrelated condition.

The PDP model seemingly cannot explain the interaction between orthography, phonology, and semantic relatedness. PDP models predict facilitative effects attributable to the overlap between the mappings of orthography, phonology, and semantics (see Hino et al., 2006). These effects should be facilitative across all conditions. Within the interaction itself we see no facilitative neighborhood effects in the context of priming. As can be seen from these results, the effects of orthography and phonology are mediated by the effects of semantics. Is the semantic connection between the prime and target the only important dynamic between the two? Can the orthographic or the phonological neighborhood size of a prime equally affect the processing of a target?

CHAPTER III

EXPERIMENT 2

When we read, we read for meaning. To that end, most reading is not done one word at a time. There are few instances in life that require words to be read in isolation (for the most part this task is relegated to the world of reading signs). Most reading is done in context. It is not reasonable to assume that the lexical characteristics of the words presented before a given target word might affect that target. As in the case of semantic priming, it is easy to see that reading “river” before “bank” facilitates processing not only in terms of speed but also in terms of meaning constraint.

“The fox outwitted the chicken,” and “The fox outwitted the clever chicken,” contain the almost the same words and the same grammatical structure. The only difference between the two is the noun being modified by “clever.” Most studies examining lexical characteristics would look at how “chicken” would be processed in isolation. It is clear, however, that the words around “chicken” should also be incorporated into its processing. “Clever” changes the meaning, not only of the sentence, but of the object being identified. Clearly, this is part of the reasoning in priming tasks. Priming adds the additional component of meaning. Meaning is not the only lexical attribute that “clever” brings to processing. “Clever” has its own orthographic and phonological neighborhood. Examining the models discussed in this paper, like the DRC, MROM, and PDP models, it is clear that ALL of these models incorporate orthography, phonology, and meaning, into processing in visual word recognition. Clearly, this should not only apply to the word being read in isolation, but also visual word recognition as a whole. It is logical to assume that if the meaning of one word affects the next word being processing, and orthography and phonology are equally important components, they should also be important in processing subsequent words.

Locker et al. (2003) used a fully interconnected model of orthography, phonology, and semantics to explain not only how semantics affects processing but to examine how the connectivity between words affects processing. They found that ambiguous words were processed more quickly than non-ambiguous words. They also found that participants responded more quickly to words with high meaning relatedness (the number of words with related meanings) but only when the targets were also high-connectivity words (the number of items in the semantic set that are also connected to one another). It would be interesting to examine whether lexical characteristics other than meaning might affect processing of the.

Part of the problem is that neither the PDP model (as presented by Harm and Seidenberg, 2004) nor the DRC model (as presented by Coltheart et al., 2001) fully instantiate the three components of processing. The DRC model, specifically, includes a semantic route, but makes no claim as to how that system works or as to how it might interact with orthography or phonology. Harm and Seidenberg also point out that they must add a second representation of orthography for their model to handle integrating the three components.   All of the models discussed thus far do include representations of all three components while none of them discuss how these three systems interact. In essence, there are very few studies that attempt to demonstrate behaviorally how these three components interact (see Reimer et al., 2008).

The second study enables a comparison between the previously discussed models of visual word recognition and a fourth model. This fourth model is known as an attractor network and is characterized by the description given by Joordens and Becker (1997). Joordens and Becker presented an attractor model as a connectionist network whereby the connections are used to settle into a stable set. An attractor network may have multiple layers and each of these layers may be used to direct movement in the model from input into the stable attractor that will become the output. One layer might represent the orthography of a stimulus, a second layer might represent phonology, and a third layer might represent semantic information. Attractor models have been able to accurately retrieve semantic information based on orthographic inputs.

Joordens and Becker (1997) implemented the attractor network to account for long-term semantic priming. In their study, Joordens and Becker manipulated the number of intervening items presented between the prime and the target in a semantic priming task. Generally speaking, as the number of intervening items between prime and target increases, the overall priming effect tends to be diminished. However, by increasing the reliance on specific variables, Joordens and Becker were able to maintain priming effects with as many as eight intervening items.

If the prime was a word from a large (orthographic or phonological) neighborhood, the attractor and more nodes are likely to be activated by that prime. This increases the likelihood of overlap between the attractor area for the prime and the attractor area of the target (even if they are unrelated). Subsequently, some learning would have occurred and processing should be faster for the corresponding targets. However, when a prime is from a small (orthographic or phonological) neighborhood there is less chance of overlap between attractor areas of the prime and the target. The target, then, cannot be aided by the weight change caused by the prime and learning must start from scratch. Therefore, not only should the neighborhood size of the target affect target processing, but also the neighborhood size of the prime may affect target processing.

Locker et al. (2003) seem to be arguing for this interactive attractor model. Their study demonstrated that specific characteristics of words and how those characteristics interact with other items in the set affect processing. Ultimately, in an attractor model this extends not only to semantics, but to orthography and phonology as well in terms of the interconnectivity across all three lexical characteristics.

Mirman and Magnuson (2008) also used a lexical decision priming task to demonstrate how different measures of semantic relatedness affect processing. In attractor models, the distance between different nodes is discussed as one possible explanation for differences in processing. This node distance can be equated to how closely two items are in terms of feature overlap. Words with more features in common with the target are nearer the attractor than words with fewer features in common. In their study, they were examining semantic features. They found that processing was slower for words with dense near semantic neighborhoods (heavy feature overlap) and faster for dense distant semantic neighborhoods. Effects were either facilitative or inhibitive based on the amount of feature overlap between the prime and target.

Seemingly, the IA and DRC models would have difficulty explaining how a prime differing in neighborhood size would affect the following target. According to these models, in using an associatively related prime, a participant would be promoted to rely on unit level activation. In this case, we would expect to see inhibition based on the neighborhood size of the target in the related condition. However, the unrelated condition places no such emphasis on unit level activation and we can expect to see facilitation of large neighborhood size in the unrelated condition. Again, these predictions are based on how the target is read. An attractor model would go further to indicate that there should be more to processing than just whether the prime and target are related or not, but how much feature overlap is there between them. By replicating Experiment 1 with a reversal of the prime-target pair, we can evaluate whether there is processing happening that can be attributed to the prime. By using the same stimuli from Experiment 1, whereby the target now becomes the prime, the prime is now manipulated based on the size of the orthographic phonological neighborhoods and relatedness.

Method

Subjects

Ninety-six English speakers selected from the University of Kansas General Psychology subject pool or participants for extra credit from Psychological Statistics were used. All participants were asked to report whether or not they have normal or corrected-to-normal vision.

Stimuli

The same stimuli from Experiment 1 were used, however, all primes became targets and all targets became primes (except in the nonword control conditions). Every target was paired with a related prime. The prime-target pairs were orthogonally crossed with respect to orthographic and phonological neighborhood size. Also, each target was paired with an unrelated prime. The unrelated primes were derived from the primes of other targets in the study that are not semantically related to the new target. This allowed for an examination of semantic relatedness, orthographic neighborhood size, and phonological neighborhood size. The same pairings from Experiment 1 were used except items labeled as primes in Experiment 1 are targets in Experiment 2 and items labeled as targets in Experiment 1 are the primes for Experiment 2.

Design and Procedure

This was a 2 x 2 x 2 x 3 design where orthographic neighborhood size, phonological neighborhood size, and semantic relatedness are compared across three

SOAs (100, 300, and 500 ms). The procedure was the same as Experiment 1 except now the manipulation is on the prime as opposed to the target.

Results and discussion

All analyses are based on correct responses to the 92 experimental items of each list. Outliers were defined separately for each SOA. The mean and standard deviation for each of the three SOAs were calculated. If a response was more than two standard deviations above or below the mean, it was determined to be an outlier and was removed from the analysis. To fill in missing data, SPSS was used to perform a series mean transformation on the missing values. All analyses were performed on this transformed dataset. Given that the items used in this study were not random, tests on items as random variables were not conducted (see Reimer et al., 2008).

Using the reaction times as the dependent variable, a 2 (orthographic neighborhood size) x 2 (phonological neighborhood size) x 2 (relatedness) x 3 (SOA) repeated measures ANOVA was performed. All values are significant at $p < .05$ unless otherwise noted.

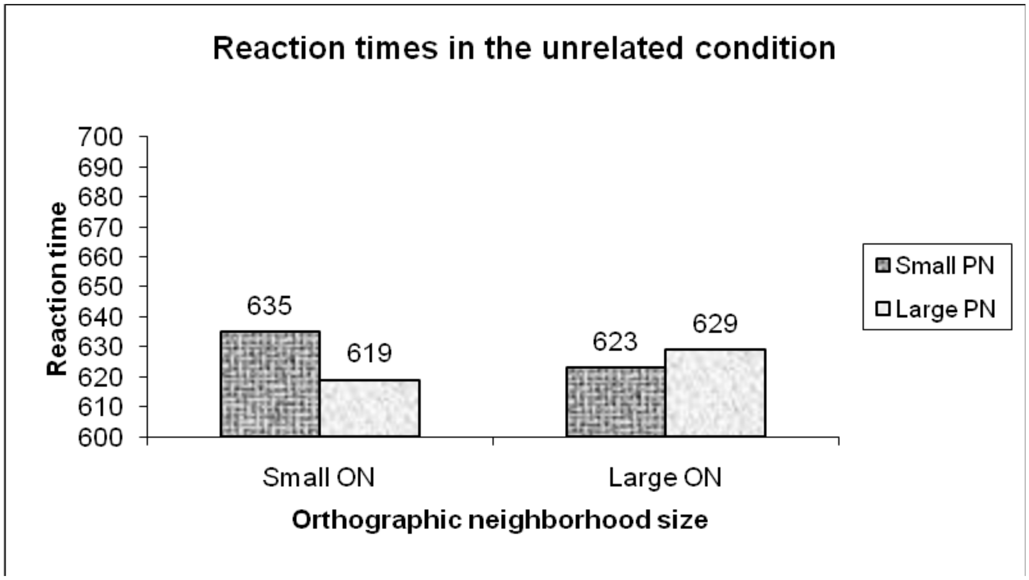
The ANOVA on the reaction times showed a main effect of relatedness, $F(1, 95) = 4.62$. Targets paired with a related prime were processed faster than those paired with an unrelated prime (7 ms). There was also a significant main effect of SOA, $F(2, 95) = 16.14$. A Bonferroni post hoc comparison showed that targets processed at 100 ms were processed more slowly than the targets processed at either a 300 ms SOA or targets processed at a 500 ms SOA.

There was also a significant interaction between orthographic neighborhood size, phonological neighborhood size, and relatedness, F (1, 95) = 9.18. See Figure 5 for a graph of this relationship. A follow-up ANOVA of simple effects was conducted looking at orthographic and phonological neighborhood effects separately for related and unrelated targets. There was a marginally significant interaction found between orthographic and phonological neighborhood size in the related condition, F (1, 95) = 3.58, p = .06. This interaction was further examined by comparing targets primed by words from large and small phonological neighborhoods, separately for large and small orthographic neighborhood primes. In the related condition, targets paired with words from a small orthographic and a small phonological neighborhood were processed more quickly than any other types of words. Further, targets paired with words from a large orthographic neighborhood were marginally different from those paired with a word from a small orthographic neighborhood F (1, 95) = 3.62, p =.06. Specifically, targets paired with words from a large orthographic neighborhood were processed more slowly than targets paired with words from a large orthographic neighborhood. There were no significant effects of phonology found in the follow-up analyses.

In the unrelated condition, there was also a marginally significant interaction between orthographic and phonological neighborhood size, F (1, 95) = 3.1, p = .082. However, upon breaking the simple effects down further, there were no significant differences between orthography or phonology in the unrelated condition. The pattern of results was such that words paired with targets from small orthographic and phonological neighborhoods and words paired with targets from large orthographic and phonological neighborhoods were processed more slowly than words paired with targets from a mixture of neighborhood sizes.

All other comparisons, both main effects and interactions, were not significant. Both the main effect of orthography (F (1, 95) = 1.35) and phonology (F (1, 95) = .46) were in this category. Also, the two-way interactions of orthography by phonology (F (1, 95) = .16), orthography by relatedness (F (1, 95) = 1.37), phonology by relatedness (F (1, 95) = .79), orthography by SOA (F (2, 94) = .41), phonology by SOA (F (2, 94) = .27), and relatedness by SOA (F(2, 94) = .69) were not significant. The three-way interactions of orthography by phonology by SOA (F (2, 94) = 1.11), orthography by relatedness by SOA (F (2, 94) = 1.53), and phonology by relatedness by SOA (F (2, 94) = .2) were also not significant. Finally, the four way interaction of orthography by phonology by relatedness by SOA interaction was not significant, F (2, 94) = .26.

Using accuracy as the dependent variable, a 2 (orthographic neighborhood size) x 2 (phonological neighborhood size) x 2 (relatedness) x 3 (SOA) repeated measures ANOVA was performed. All values are significant at $p < .05$ unless otherwise noted. There was a significant four- way interaction between orthography, phonology, relatedness, and SOA, F (2, 94) = 3.51. A follow-up ANOVA examining the interaction between orthography, phonology, and relatedness at each of the three SOAs showed that only at the 100 ms SOA was there a significant interaction, F (1, 95) = 5.002, p = .028.



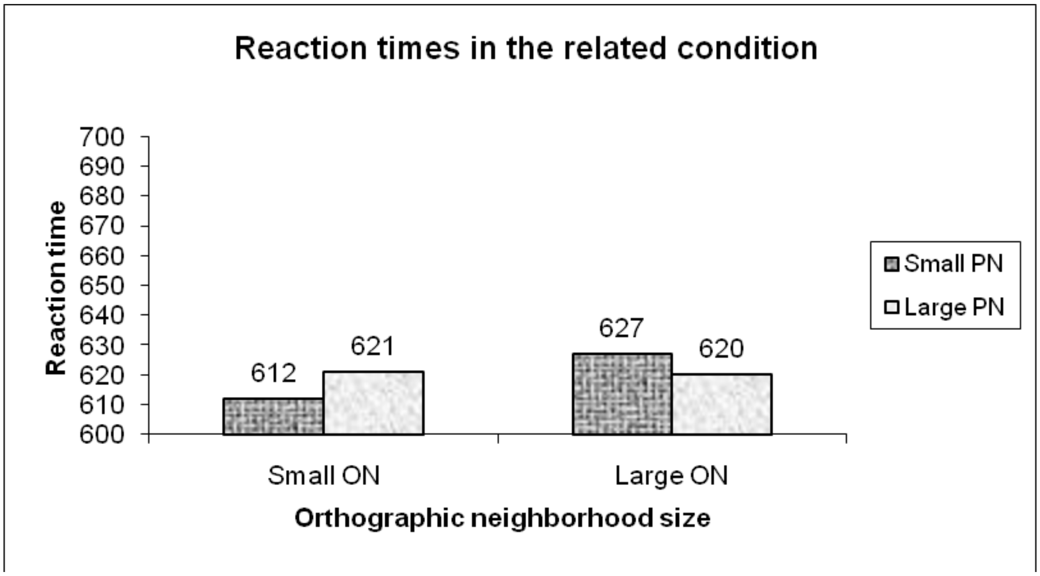


Figure 6: Interaction between orthographic neighborhood size, phonological neighborhood size, and relatedness

There is a clear interaction between the processing of semantics, orthography, and phonology. This is in contrast to Reimer et al.'s (2008) study where they found a significant facilitative priming effect for orthographically mediated words but not for homophonically mediated words. In the context of Experiment 2, it is the combination of being a prime from both a small orthographic and phonological neighborhood that is important in processing (both in reaction time and in accuracy). The lexical characteristics of the prime are made available as soon as it is viewed. Once the target is presented, the information from that prime feeds forward to aid in processing of the target. If the corresponding neighborhoods are both small and the target is a related, then processing is speeded. The interaction between phonology and orthography is as important as how orthography and semantics, or semantics and phonology feed forward and backward to one another.

Mirman and Magnuson (2008) use attractor networks and the distance between different nodes as one possible explanation for differences in processing time. This node distance can be equated to how closely two items are in terms of feature overlap. Words with more features in common are nearer the attractor than words with fewer features. When a related prime is present there is a potential for a great deal of feature overlap between the prime and the target. The attractor that the model essentially wants to settle into is the target. The model needs to move very little to settle onto the new attractor when the corresponding prime is processed. When the prime and target are related, it does not matter if there is feature overlap to the orthographic or phonological systems. The model can rely on the semantic feature overlap to make its decision. Therefore, we see a facilitative effect for the prime being related to the target and the target is processed more quickly.

The model should be able to use any of the three systems to settle into the new attractor. When either the phonological or the orthographic neighborhood is large, the attractor network should be able to rely on that information to settle. If one were to think of an attractor model in a three dimensional space then one could imagine that semantics, phonology, and orthography each correspond to a different dimension. When any of at least two of the dimensions intersect or overlap one could equate that with feature overlap. The more overlap there is, the faster that the attractor model can settle. When a prime from a large ON and/or a large PN is activated the correlated space of those two items is also activated, along with the corresponding meaning nodes. Once the target is processed, there is a high likelihood that the target would have been in the corresponding activated three dimensional space that makes up the attractor network (phonology, orthography, and semantics). When the target and prime are associates, this is always true. When the prime is unrelated or when the prime is related but the prime comes from a large orthographic or a large phonological neighborhood, we would expect to see the model settle into the attractor more quickly based on having a prime or the prime being from a large orthographic or phonological neighborhood. This is not what we found. The problem is in explaining how in the context of a large orthographic and/or a large phonological neighborhood (with or without a prime) we do not see a facilitative effect whereby being from a large orthographic or phonological neighborhood speeds processing.

Seemingly, the IA and DRC models would have difficulty explaining how a prime is only facilitative when the prime comes from a small neighborhood. According to these models, in using an associatively related prime, a participant must rely on unit level activation. As stated in Experiment 1, when the orthographic and/or phonological neighborhood size is large the participant can rely on global activation which facilitates processing. When both the orthographic and the phonological neighborhood size are small, targets cannot benefit from global activation because of the small neighborhood size; and the participant must rely on unit level activation. Based on these predictions, we would not expect to see a significant priming effect when neighborhood size is small for both orthography and phonology. That is, however, exactly what was found. Based on these models, it is not clear how an unrelated prime's neighborhood size could affect the processing of a target at all. The neighborhood size of a prime in no way affects how the model processes the target in terms of global or unit level activation. In fact, it is not clear how these models could account for the results in Experiment 2. Again, it is the PDP model that seems the least capable of explaining these results. In terms of this model, any activation and overlap should facilitate processing. However, in the case of the three-way interaction, there is clearly a lack of facilitative priming effects (especially in the unrelated condition.

CHAPTER IV

Discussion

It is not clear if current models of visual word recognition are capable of accounting for the interaction among these three factors. While all four models discussed in this paper (PDP, MROM, DRC, and attractor models) incorporate all three aspects into the models, none of them can wholly explain the results of these experiments. These three lexical aspects (meaning, orthography, and phonology) are clearly important in reading. At this time there seems to be little work and little attention being devoted to understanding how we read in context as opposed to one word at a time. In essence, even the most common models of visual word recognition seem to have difficulty accounting for interaction of these three most rudimentary lexical attributes. Perhaps future work needs to begin to focus more on interacting reading components as opposed to individual components because sometimes the whole really is more important than the sum of its parts.

Several things, in particular, seem to become apparent as a result of this study. First of all, it is important to look at lexical characteristics in the context of one another as well as in isolation. The results of this study seem to clearly indicate that it is not only the characteristics of the target that affects processing. The characteristics of the prime are similarly important to the processing of the target. In terms of semantics, this seems to make sense. It is logical to assume that the prime affects how the target is processed (largely, this is what priming is). It is less easy to assume that other lexical characteristics of the prime (specifically orthography and phonology, in this case) also effects processing of the target.

The significant three-way interaction between orthography, phonology, and semantics, in both studies, seems to suggest that not only do these three characteristics affect processing but that processing is mediated in an almost hierarchical fashion. Semantics (priming) is only facilitative in the context of both a small phonological and a small orthographic neighborhood. This seems to suggest that when the participant has access to all three of these lexical characteristics, they first rely on orthography (having more orthographic neighbors speeds processing). When the orthographic neighborhood is small, the focus is then switched to phonology (having more phonological neighborhoods speeds processing). Only when both of these routes fail, do we see processing speeded by a related prime.

There is at least one disclaimer to this claim. For the purpose of this study, words were characterized as being from a small orthographic neighborhood by way of doing a mean split (all words below the mean were characterized as being from a small neighborhood and all words above the mean were characterized as being from a large neighborhood). The same process was followed to generate small and large phonological neighborhoods. As such, there were different cut-off points for what constituted being from a large as opposed to a small neighborhood by basis of the lexical characteristic. The mean orthographic neighborhood size was 4 while the mean phonological neighborhood size was 10. Consequently, what was considered to be a word from a large orthographic neighborhood might be considered as having been from a small phonological neighborhood. This difference in absolute size might have attributed to the significant main effect of phonology but the lack of a main effect of orthography. This could be especially important in the context of the three-way interaction that included phonology. One potential way to get around this in future experiments would be to standardize (compute z-scores) for both phonological and orthographic neighborhood size and make comparisons based on those z-scores. This could potentially account for why this experiment failed to find a facilitative effect of orthography while several others have found such an affect (see Reimer et al., 2008).

Also of interest was the orthographic neighborhood size by SOA manipulation. In this context of this study, being from a large orthographic neighborhood was only facilitative at the 500 ms SOA. In the context of this study, 500 ms was considered to be a long prime duration. Based on the work of Schiller (2007), this was a surprising result. Schiller found that orthographic neighborhood size is most influential at early SOAs while phonology is important at later SOAs. We found no interaction between phonology and SOA and orthography was most influential at the long SOA. It is possible that this discrepancy in findings is based on how “late processing” is defined. Reimer et al. (2008) found facilitative effects of orthography at 413 ms. These results seem congruent with our findings at 500 ms. It might, then, be reasonable to classify 500 ms as early processing. One way to get a better understanding of the time course of processing and to directly test this theory would be to use a longer SOA (750 to 1000 ms, for example).

Interestingly, a pilot study done in anticipation of this dissertation addresses this issue. A manipulation like the one completed in Experiment 2 was done using a 750 ms SOA. In that experiment, there was a marginally significant three-way interaction between orthography, phonology, and semantics (similar to the ones found in Experiment 1 and 2), F (1, 39) = 3.6, p = .066. This lends credibility to the idea that this same structure might benefit from being tested at one or two longer SOAs. This would provide a better picture in terms of the time course of processing.

I have attempted to make the case that orthography is an important component to visual word recognition. I have also attempted to make the point that orthography should not be studied alone. There are many other variables that affect visual word recognition; meaning and phonology are but two of the variables that affect lexical processing. As clearly demonstrated in both Experiments 1 and 2, there is an interaction between semantic relatedness and phonological and orthographic neighborhood size and how those factors affect processing. Perhaps the most important aspect of this interaction is that it is not only the phonological and orthographic characteristics of the target that is important. The lexical characteristics of the prime are also affecting the target, and perhaps more importantly, they are affecting the interaction among these three variables.

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Appendix A

Reaction Times Per Subject for Each Cell: Experiment 1

SUBJECT	RT0R50	RT0R250	RT0R450	RT0U50	RT0U250	RT0U450
1	667	567	640	698	629	613
2	595	573	553	560	690	653
3	567	562	580	640	597	694
5	613	695	586	501	760	680
6	437	511	546	668	527	576
7	823	730	678	722	616	778
8	679	649	659	698	935	694
9	655	684	678	631	685	870
10	702	666	635	874	696	820
11	573	590	714	880	690	691
12	649	616	856	693	781	714
13	765	635	713	610	690	683
14	724	722	853	792	751	694
15	864	961	585	698	634	869
16	679	480	540	904	685	730
17	504	653	616	620	952	543
18	463	607	659	578	716	503
19	679	737	763	683	693	642
20	617	653	660	567	608	724
21	541	440	659	455	472	547
22	576	843	812	748	641	723
23	832	725	710	739	587	672
24	679	680	745	712	740	674
25	565	560	564	698	550	694
26	745	635	659	751	690	777
27	638	602	785	611	600	694
28	801	669	550	627	729	616
29	724	870	773	762	735	736
31	717	575	622	501	562	612
32	679	653	659	698	690	694
33	781	860	658	948	931	954
34	790	611	540	852	679	709
36	687	598	657	790	897	834
39	618	515	517	698	721	803
40	679	595	567	687	587	673

41	711	653	659	711	822	674
43	679	653	780	783	845	591
45	635	634	659	543	457	543
46	621	675	799	829	690	637
48	984	748	677	655	832	600
49	652	577	723	698	635	587
50	713	654	659	854	690	839
51	704	714	769	576	690	740
52	626	550	615	700	524	509
53	597	562	515	931	672	694
55	640	532	609	548	756	704
56	725	903	630	600	557	675
58	934	717	855	698	827	812
59	532	705	473	558	649	622
61	647	865	695	643	690	744
62	598	498	597	821	684	694
63	707	823	651	698	757	848
64	679	586	662	720	735	637
65	597	653	702	665	710	698
66	511	677	659	505	546	611
68	728	653	650	633	627	628
69	639	778	659	869	598	1006
70	537	683	636	563	582	662
71	745	646	659	725	870	768
72	641	562	553	560	752	495
82	679	568	515	686	580	486
153	849	653	658	586	574	664
83	558	638	608	651	644	729
84	646	601	828	762	815	831
154	802	510	831	730	690	621
85	692	525	564	745	690	561
86	791	544	712	582	702	694
87	486	577	659	597	873	872
88	690	653	710	793	715	510
89	848	653	659	698	690	783
90	589	584	623	698	593	548
91	732	806	659	893	690	656
92	752	589	727	604	704	694
93	630	579	515	587	807	634
94	733	474	681	785	542	525

95	604	557	466	590	554	646
96	668	576	570	698	719	538
97	580	563	683	662	626	585
98	747	640	656	698	773	727
99	679	565	671	738	672	728
100	739	653	533	818	826	633
101	679	797	555	766	532	649
102	683	663	659	721	538	576
103	865	551	557	541	550	637
105	859	1026	659	835	984	1023
107	717	621	705	689	687	768
108	535	660	838	693	552	555
109	827	929	631	819	690	871
110	814	825	659	777	690	898
112	492	730	659	565	757	865
113	592	653	749	695	629	572
114	762	701	659	994	690	841
124	628	703	600	819	723	694
141	849	748	595	738	859	694
145	593	542	937	728	702	775
152	679	653	773	682	848	918

SUBJECT	RT1R50	RT1R250	RT1R450	RT1U50	RT1U250	RT1U450
1	552	688	607	626	523	849
2	565	433	676	448	478	550
3	544	549	562	493	511	522
5	629	626	567	646	800	694
6	530	504	659	514	634	641
7	666	626	771	637	528	622
8	653	596	767	775	634	638
9	685	583	659	646	602	535
10	676	614	822	741	817	663
11	780	513	570	597	700	622
12	622	711	655	758	654	638
13	727	626	742	612	772	691
14	683	693	659	618	541	585
15	653	737	657	646	589	689
16	660	647	576	566	532	658
17	694	547	575	564	530	536

18	729	600	676	578	592	630
19	794	770	612	645	634	655
20	608	595	507	642	603	622
21	477	724	412	646	580	579
22	670	582	659	717	634	612
23	653	533	606	741	636	622
24	680	626	707	646	767	655
25	532	441	504	539	551	518
26	799	626	927	613	818	777
27	500	637	841	619	483	584
28	653	638	652	585	660	622
29	605	626	741	646	731	564
31	653	539	545	620	634	560
32	653	626	918	646	634	622
33	653	781	659	646	737	788
34	654	634	621	692	773	667
36	636	611	665	848	760	803
39	653	603	719	584	585	553
40	564	558	595	544	625	547
41	673	611	565	610	491	788
43	614	674	744	918	634	515
45	529	525	414	646	526	545
46	603	647	659	671	634	900
48	562	626	659	646	634	778
49	569	535	833	785	574	476
50	786	583	538	918	822	576
51	826	626	901	646	989	730
52	653	569	499	616	587	622
53	492	719	730	600	468	486
55	653	524	539	611	634	529
56	651	626	570	646	582	622
58	708	927	731	829	634	789
59	597	645	524	489	573	633
61	764	626	585	632	788	638
62	533	649	659	619	520	697
63	653	641	780	744	686	722
64	824	626	760	646	585	707
65	642	622	699	640	659	605
66	516	438	559	484	470	576
68	636	554	606	577	670	622

69	786	654	1015	646	712	745
70	480	632	659	579	634	462
71	653	726	718	671	693	622
72	612	626	507	646	512	555
82	1026	501	562	579	634	503
153	579	528	659	669	634	523
83	668	771	659	646	624	509
84	576	732	659	693	634	638
154	637	612	543	601	596	574
85	677	626	587	723	521	577
86	550	539	659	599	629	486
87	586	569	552	736	612	576
88	590	783	558	572	669	622
89	653	810	742	646	788	622
90	688	447	553	784	577	496
91	695	585	628	730	752	767
92	571	728	679	567	634	642
93	562	626	564	646	539	547
94	653	605	508	509	634	535
95	612	626	563	558	545	622
96	825	650	903	630	514	693
97	617	572	559	560	590	554
98	653	840	721	582	596	771
99	609	663	679	656	649	566
100	677	613	694	825	657	717
101	500	624	863	753	634	635
102	604	586	599	646	602	565
103	687	610	659	573	634	497
105	653	626	837	646	706	622
107	625	690	659	622	634	652
108	773	619	659	646	643	574
109	996	603	943	816	658	525
110	743	626	665	671	689	743
112	674	592	539	612	589	663
113	854	736	640	602	779	622
114	653	706	635	709	694	622
124	801	654	659	650	615	590
141	653	679	782	646	757	622
145	567	637	725	674	590	560
152	738	626	641	646	634	657

SUBJECT	RT2R50	RT2R250	RT2R450	RT2U50	RT2U250	RT2U450
1	517	568	631	813	647	740
2	671	427	512	630	599	645
3	564	911	592	687	580	741
5	640	611	559	489	647	633
6	456	618	577	627	475	645
7	549	472	517	498	634	512
8	599	719	649	730	686	664
9	904	578	555	675	902	554
10	732	580	581	687	642	599
11	636	568	651	510	647	767
12	659	603	608	835	503	645
13	810	715	643	809	718	747
14	570	592	559	687	903	535
15	493	818	589	798	647	786
16	712	555	588	622	539	582
17	540	614	584	594	551	611
18	730	689	633	596	614	624
19	730	640	564	973	780	632
20	567	608	626	623	577	774
21	493	509	519	582	578	490
22	802	624	776	744	781	787
23	606	714	809	526	626	616
24	860	587	768	697	798	759
25	576	472	678	597	647	513
26	664	859	819	710	692	645
27	612	758	487	687	521	590
28	589	435	574	687	591	551
29	629	665	643	680	647	663
31	560	709	587	592	647	463
32	989	644	1013	687	989	645
33	642	807	677	702	812	979
34	849	712	693	687	745	636
36	712	689	835	868	504	645
39	821	683	839	699	721	1026
40	561	546	528	611	518	528
41	664	644	644	782	607	696
43	597	567	643	656	779	667

45	530	435	471	603	475	488
46	821	583	859	754	644	597
48	588	633	929	631	466	725
49	543	532	828	575	647	586
50	784	644	656	686	717	645
51	664	648	603	730	647	773
52	617	453	712	687	541	517
53	573	512	624	687	544	716
55	597	709	601	713	611	493
56	681	575	608	672	613	659
58	664	796	773	687	747	656
59	539	656	582	567	647	525
61	732	995	639	687	741	868
62	602	722	615	1023	744	668
63	948	639	748	604	648	770
64	682	588	643	791	850	599
65	605	582	611	626	649	611
66	444	499	443	596	436	459
68	846	622	649	562	794	642
69	502	644	747	687	817	645
70	598	498	551	621	489	556
71	711	686	654	668	725	701
72	738	549	844	516	487	508
82	641	523	415	560	580	494
153	601	662	427	616	488	645
83	618	464	452	839	586	471
84	988	532	646	771	636	645
154	655	656	522	817	647	603
85	724	487	833	698	650	783
86	563	608	533	703	716	588
87	516	611	681	518	561	516
88	496	716	648	847	812	778
89	846	1017	665	914	752	785
90	579	571	447	611	647	546
91	704	985	708	710	635	645
92	665	983	609	687	566	636
93	736	636	638	586	647	604
94	574	567	572	767	566	645
95	598	643	465	492	499	604
96	628	790	540	687	677	586

97	604	480	557	511	509	645
98	884	503	1015	875	917	559
99	672	627	701	697	677	766
100	675	728	653	712	746	700
101	631	815	995	519	670	607
102	743	644	538	712	547	559
103	712	567	627	678	470	704
105	962	644	658	687	537	755
107	510	614	611	689	635	645
108	472	597	494	594	570	638
109	661	729	737	961	647	734
110	711	685	783	924	877	645
112	634	681	587	573	620	602
113	745	666	532	706	651	562
114	561	717	559	853	721	554
124	847	851	587	929	768	706
141	812	721	927	687	718	713
145	699	566	613	661	442	645
152	801	800	643	733	582	842

SUBJECT	RT3R50	RT3R250	RT3R450	RT3U50	RT3U250	RT3U450
1	684	755	816	589	595	595
2	538	710	615	724	676	549
3	584	513	577	535	564	519
5	802	802	808	868	600	604
6	740	639	485	629	574	527
7	820	595	608	581	604	632
8	814	657	949	716	676	678
9	649	467	626	663	776	590
10	648	919	614	661	605	623
11	635	653	639	599	768	602
12	647	595	702	570	661	674
13	655	651	536	730	873	604
14	669	653	576	758	666	730
15	652	516	639	634	608	598
16	655	638	621	550	679	772
17	568	653	595	473	819	664
18	692	523	639	637	595	509
19	606	507	639	791	747	745

20	583	652	700	690	680	636
21	813	578	632	775	676	524
22	725	629	627	663	776	799
23	770	651	579	549	676	706
24	723	794	675	699	695	632
25	609	513	558	505	520	552
26	618	934	685	712	685	594
27	528	435	524	529	551	497
28	741	931	543	587	491	546
29	611	565	761	759	596	544
31	534	597	566	536	676	664
32	929	886	639	663	894	632
33	789	788	770	663	676	889
34	526	566	673	566	669	550
36	744	660	648	745	688	585
39	634	841	639	560	961	698
40	655	520	710	486	607	501
41	875	653	718	760	581	645
43	822	908	633	727	966	608
45	487	548	489	657	688	526
46	691	643	639	663	790	612
48	710	563	661	765	610	632
49	862	632	639	719	863	649
50	607	1019	650	707	835	784
51	805	718	614	710	912	665
52	719	469	456	619	524	626
53	637	574	661	953	606	919
55	515	747	458	595	676	495
56	559	667	609	668	612	632
58	879	769	835	663	835	554
59	553	529	525	517	483	514
61	655	692	780	735	730	671
62	589	653	635	611	642	569
63	656	640	639	605	614	552
64	655	707	712	788	810	817
65	642	653	585	602	662	632
66	527	467	639	472	411	462
68	705	617	597	706	757	628
69	655	956	452	786	810	828
70	605	515	523	663	670	586

71	684	676	702	668	676	703
72	655	550	504	677	537	632
82	476	554	804	636	529	417
153	618	505	664	527	616	557
83	704	508	661	663	531	638
84	642	706	639	754	754	587
154	615	542	821	832	715	502
85	655	495	455	813	485	602
86	594	653	508	688	505	433
87	508	535	639	584	457	468
88	544	718	577	830	791	764
89	707	736	595	789	676	688
90	534	583	483	605	616	617
91	655	692	839	875	967	637
92	604	596	527	519	667	632
93	592	732	619	594	563	542
94	550	564	639	571	676	628
95	565	691	518	549	537	632
96	584	794	495	632	612	762
97	545	495	553	657	539	660
98	627	657	639	712	792	636
99	655	642	588	611	680	613
100	840	653	809	1036	901	852
101	676	623	627	831	831	692
102	639	588	636	647	623	549
103	780	665	708	663	672	512
105	655	929	842	497	959	539
107	642	582	748	558	625	545
108	598	464	618	663	703	562
109	597	689	708	678	668	634
110	655	752	803	672	676	905
112	681	741	639	730	692	599
113	501	523	645	444	586	779
114	717	708	628	636	676	700
124	608	653	582	761	696	676
141	703	856	715	689	581	983
145	591	631	517	643	583	825
152	705	653	881	657	788	632

Appendix B

Reaction Times Per Subject for Each Cell: Experiment 2

SUBJECT	RT0R50	RT0R250	RT0R450	RT0U50	RT0U250	RT0U450
1	648	450	502	650	620	582
2	579	565	656	650	656	586
3	831	605	592	650	655	679
4	606	605	567	650	582	566
7	624	518	581	646	621	613
8	763	837	787	655	621	734
10	651	767	724	617	621	621
11	619	646	748	722	526	633
12	622	713	582	697	602	633
14	550	613	550	540	580	633
16	671	647	660	650	667	645
17	728	609	610	650	649	718
18	594	630	489	725	817	581
19	581	431	610	794	553	477
21	763	811	864	609	916	762
22	466	464	610	523	472	543
23	571	490	773	780	752	677
24	773	634	610	669	628	690
26	630	605	607	708	653	660
27	657	653	713	710	689	985
28	563	552	558	650	737	584
29	526	566	589	650	594	515
31	577	605	799	766	750	647
32	571	659	638	650	566	696
34	485	416	528	585	495	633
35	648	688	596	650	724	633
38	622	576	519	558	449	522
39	545	615	638	728	522	566
40	697	754	709	734	621	743
41	611	525	563	656	606	799
43	538	548	518	661	710	633
44	899	578	522	717	580	633
46	763	603	639	650	621	540
48	674	609	452	727	503	963
49	622	526	528	600	567	515

51	574	640	513	554	577	686
52	524	605	529	566	466	594
53	513	540	571	873	548	665
54	537	455	469	530	557	596
56	630	504	787	734	757	958
57	482	510	466	566	434	472
58	545	736	639	684	580	540
59	667	477	887	633	569	802
61	584	631	591	724	621	627
62	778	794	650	611	621	715
63	531	687	715	735	621	713
64	683	678	688	607	621	628
66	573	544	507	717	692	633
68	768	768	687	719	730	633
71	783	600	588	650	628	715
72	661	631	582	650	742	637
73	658	706	626	650	611	636
74	614	848	595	650	626	611
78	622	584	613	564	621	683
82	660	605	661	714	581	694
83	796	605	452	519	488	482
84	556	605	596	617	542	587
87	490	434	610	465	478	462
88	663	555	610	685	666	538
89	630	601	610	842	594	612
91	622	621	535	816	621	639
93	622	681	607	548	532	550
94	622	481	437	493	451	556
95	622	490	750	584	760	577
96	587	605	529	645	533	667
98	622	605	687	493	557	593
99	507	605	496	537	489	568
101	677	701	610	650	756	719
102	723	556	610	748	498	489
105	673	550	610	688	677	596
106	536	485	627	650	561	621
107	465	462	521	754	439	633
109	469	435	497	449	652	552
111	809	773	773	746	777	796
112	644	667	578	655	774	653

113	584	539	836	578	621	506
114	498	613	443	554	552	524
116	535	629	661	696	654	633
118	539	563	559	632	643	636
119	517	594	568	703	576	547
120	537	563	519	556	549	597
121	553	693	774	478	621	516
129	552	525	610	684	614	870
134	602	821	684	733	590	633
136	622	785	601	640	575	619
137	727	605	561	697	664	836
138	501	572	610	531	591	511
140	635	605	582	806	694	547
141	654	540	610	555	570	626
145	713	625	508	595	779	533
148	540	623	629	634	633	633
149	661	512	714	675	707	633
151	622	434	540	511	610	569
154	903	925	659	855	756	678
158	622	605	661	804	726	763
159	596	514	536	488	930	574

SUBJECT	RT1R50	RT1R250	RT1R450	RT1U50	RT1U250	RT1U450
1	521	623	610	562	507	655
2	636	663	733	543	634	495
3	517	536	767	822	602	607
4	639	688	676	598	531	620
7	653	579	753	798	606	583
8	665	587	643	646	568	655
10	764	705	651	637	625	589
11	681	726	506	695	586	734
12	695	805	560	637	718	613
14	531	557	588	580	641	831
16	624	559	694	742	648	613
17	624	707	662	579	601	613
18	624	593	609	717	684	613
19	624	558	551	491	571	613
21	895	621	755	637	608	846
22	533	621	451	637	555	465

23	627	621	615	637	464	694
24	763	621	686	637	795	710
26	641	653	617	677	608	803
27	783	756	617	761	608	873
28	674	599	617	599	608	613
29	693	560	617	644	608	754
31	624	621	640	571	608	661
32	624	835	625	601	608	658
34	624	496	448	732	608	471
35	624	747	584	541	608	682
38	586	621	739	571	463	613
39	666	621	708	563	737	613
40	724	621	796	790	716	613
41	624	677	617	637	555	635
43	680	525	617	637	593	567
44	735	581	617	637	644	579
46	590	623	658	615	578	532
48	572	645	558	599	556	533
49	611	700	617	646	719	458
51	539	547	581	567	638	561
52	554	728	571	620	521	595
53	640	734	647	631	772	613
54	587	540	574	512	522	570
56	563	607	621	617	608	582
57	624	582	506	576	422	561
58	520	490	682	532	520	579
59	534	604	577	639	496	556
61	591	621	640	753	431	555
62	626	621	616	675	714	615
63	570	621	697	663	656	579
64	632	621	606	662	603	656
66	561	498	617	625	543	495
68	624	732	617	740	869	709
71	624	810	722	596	727	727
72	624	610	558	585	800	648
73	624	610	761	739	690	762
74	624	649	634	778	661	623
78	606	659	663	743	582	627
82	727	612	550	527	639	626
83	660	557	428	639	588	694

84	675	720	617	682	601	673
87	624	463	531	483	418	377
88	854	684	698	757	677	636
89	564	592	556	665	561	631
91	463	589	570	736	608	516
93	481	485	608	597	608	726
94	624	473	461	504	608	443
95	488	667	717	695	608	617
96	606	621	588	560	584	613
98	531	463	616	592	561	613
99	539	621	443	637	486	613
101	716	797	672	637	608	651
102	532	613	447	637	697	587
105	653	597	741	637	584	594
106	612	498	617	560	608	484
107	572	556	617	502	608	557
109	521	476	617	644	608	613
111	624	713	836	732	823	613
112	624	618	613	541	708	613
113	624	651	560	525	542	613
114	624	595	553	507	489	613
116	606	621	602	637	524	612
118	658	621	514	637	554	652
119	757	621	681	637	497	538
120	581	621	621	637	542	512
121	631	761	618	690	614	548
129	757	647	617	637	541	535
134	636	637	617	677	668	586
136	650	564	586	637	669	551
137	666	675	617	900	830	764
138	624	510	532	605	548	812
140	674	621	547	532	599	613
141	633	619	566	637	569	559
145	522	495	607	588	686	570
148	624	631	617	683	594	561
149	653	654	617	574	661	613
151	553	475	550	552	537	445
154	630	730	617	807	608	613
158	624	698	752	901	633	603
159	527	621	640	528	520	613

SUBJECT	RT2R50	RT2R250	RT2R450	RT2U50	RT2U250	RT2U450
1	481	483	475	608	617	466
2	519	638	604	606	617	648
3	682	712	523	579	617	682
4	638	546	627	646	617	725
7	601	538	681	765	617	619
8	638	581	752	827	762	619
10	688	743	699	714	619	619
11	693	758	583	634	689	617
12	746	691	789	634	622	656
14	560	623	834	634	636	673
16	668	731	635	634	588	623
17	616	641	615	634	623	608
18	658	476	765	634	680	685
19	644	607	606	634	501	528
21	751	760	720	768	617	806
22	590	462	627	491	617	435
23	710	539	772	591	617	653
24	818	780	584	580	617	766
26	658	644	682	670	626	619
27	879	636	672	707	617	619
28	744	611	589	666	604	619
29	898	544	645	700	485	619
31	689	621	778	670	753	619
32	574	695	663	608	665	714
34	638	615	574	565	617	565
35	835	501	618	845	533	696
38	576	435	452	498	517	471
39	652	716	571	543	698	619
40	820	615	569	630	793	619
41	636	598	591	634	747	532
43	600	569	574	498	673	526
44	616	670	627	666	772	763
46	604	579	492	634	620	737
48	611	689	627	634	591	570
49	699	602	754	634	585	593
51	544	540	689	699	617	666
52	664	501	613	631	617	611

53	584	615	627	808	617	697
54	658	632	574	828	617	546
56	637	655	862	635	617	619
57	490	417	613	512	501	619
58	618	608	536	538	505	619
59	598	540	557	559	739	619
61	527	564	768	639	728	700
62	586	617	694	632	733	576
63	702	705	620	598	588	619
64	610	642	743	561	645	584
66	616	556	529	623	463	607
68	742	732	694	775	625	716
71	611	871	615	740	609	586
72	534	738	606	564	518	683
73	668	696	698	706	617	618
74	574	756	626	591	699	531
78	766	686	468	583	620	900
82	627	615	614	739	825	619
83	531	615	672	536	577	655
84	567	592	640	629	578	565
87	407	417	518	461	485	407
88	651	869	615	705	762	715
89	613	615	725	807	634	598
91	699	589	627	634	516	652
93	614	649	483	554	600	613
94	607	446	486	562	433	495
95	703	667	650	593	608	632
96	629	511	524	620	633	490
98	885	520	537	488	551	585
99	474	526	555	658	522	458
101	707	717	635	624	759	744
102	520	512	606	651	511	631
105	536	646	684	565	448	688
106	661	500	530	642	584	569
107	598	495	548	571	471	508
109	648	497	463	567	511	555
111	767	763	730	762	900	720
112	466	848	783	594	665	740
113	507	591	568	632	633	651
114	596	607	478	634	467	467

116	691	586	513	718	466	521
118	549	495	702	668	487	547
119	594	613	547	634	572	561
120	548	543	569	668	573	648
121	754	625	524	699	665	619
129	812	743	830	565	753	616
134	793	632	773	666	723	606
136	943	624	627	645	695	660
137	638	615	684	743	751	733
138	553	680	563	609	537	632
140	533	506	594	725	649	681
141	547	509	458	546	546	521
145	643	558	650	634	576	558
148	537	685	575	634	694	683
149	511	547	680	653	491	610
151	508	552	612	482	490	557
154	715	787	848	598	736	695
158	691	830	754	606	832	724
159	521	434	518	483	519	441

SUBJECT	RT3R50	RT3R250	RT3R450	RT3U50	RT3U250	RT3U450
1	510	449	622	570	532	546
2	565	612	462	703	693	624
3	700	654	763	663	619	648
4	548	673	735	809	614	644
7	593	521	611	702	619	627
8	714	599	622	780	619	470
10	648	643	669	730	692	561
11	713	527	604	648	811	612
12	812	704	746	636	722	620
14	615	549	511	561	570	600
16	710	657	624	566	778	630
17	839	723	691	655	570	533
18	867	681	670	596	490	562
19	657	665	639	549	522	505
21	543	599	622	756	745	620
22	534	599	442	740	528	489
23	598	636	763	718	619	572
24	772	599	642	696	606	710

26	577	585	716	646	708	650
27	789	719	622	670	619	728
28	695	581	622	599	568	558
29	716	559	654	614	631	547
31	686	732	455	702	619	654
32	537	686	690	652	619	702
34	585	501	524	488	619	538
35	889	651	548	645	619	634
38	638	529	521	588	480	620
39	635	757	517	653	723	620
40	895	720	703	827	787	620
41	612	525	579	648	591	681
43	621	452	607	648	723	565
44	782	599	422	648	654	758
46	714	599	613	618	737	619
48	614	511	646	794	551	569
49	634	477	674	554	431	469
51	502	563	511	613	535	523
52	641	480	605	540	540	546
53	719	658	780	642	619	706
54	559	505	622	517	563	678
56	589	784	738	816	604	849
57	472	600	622	582	478	615
58	601	607	564	646	680	626
59	537	523	610	605	593	590
61	638	672	622	814	510	588
62	638	578	713	650	674	733
63	638	662	687	512	702	684
64	638	598	650	617	716	638
66	575	599	756	618	603	521
68	814	599	700	851	805	817
71	651	800	622	808	600	620
72	598	581	622	678	558	749
73	678	795	622	623	618	692
74	714	587	622	630	706	772
78	638	691	629	592	713	622
82	630	599	683	630	683	755
83	649	599	620	657	693	530
84	620	599	685	619	696	558
87	500	424	622	697	485	479

88	675	634	622	700	678	642
89	684	661	622	821	549	654
91	554	567	622	755	546	558
93	548	492	458	585	625	643
94	704	473	480	648	524	504
95	635	603	622	642	578	562
96	566	449	664	495	626	573
98	579	503	574	555	529	589
99	497	436	486	648	490	673
101	678	749	663	697	604	679
102	531	522	499	631	507	563
105	652	536	656	675	459	683
106	504	553	519	648	518	466
107	501	541	622	648	507	601
109	556	432	624	648	522	501
111	638	793	754	803	619	729
112	586	713	622	860	619	600
113	539	568	638	552	619	590
114	506	425	622	479	619	557
116	720	478	667	564	678	620
118	601	583	531	613	554	620
119	768	629	674	623	675	620
120	502	534	544	595	508	620
121	638	490	547	604	582	632
129	779	599	622	648	742	790
134	752	599	667	752	626	594
136	638	689	655	519	666	622
137	610	599	789	648	740	687
138	684	628	622	584	546	495
140	562	759	671	648	644	610
141	561	536	847	540	720	574
145	665	608	588	631	633	608
148	570	660	510	463	553	591
149	638	599	658	751	729	782
151	638	514	522	588	590	487
154	814	750	622	648	750	666
158	638	729	716	638	773	886
159	563	469	473	612	571	620