DISSERTATION

LETTER MATCHING IN WORD FAMILIARITY:

COMPARING SLOT SPECIFIC, RELATIVE POSITION, AND OVERLAP CODING APPROACHES

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ABSTRACT

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Familiarity detection is the sense that something has been encountered before, without being able to recall specifics of the encounter. Viewed as a separable process from recalling specifics, a growing body of research suggests that familiarity detection is an important cognitive process for a variety of reasons. Familiarity detection is thought to be driven by an overlap in features between stimuli stored in memory and a current stimulus. Research on familiarity detection suggests that letters are one significant contributing feature to word familiarity. An unexamined question is the extent to which letter overlap needs to occur in the same positions between existing memory representations and the current stimulus. Research on reading suggests that letters do not need to be in the exact correct location for lexical access to occur, with different theories specifying different constraints. One theory is that letter position is coded in terms of relativity; another is that letter position is coded in terms of general location with flexibility. For this dissertation, I conducted two experiments investigating how letter position processing might operate in word recognition without identification, which is thought to be a metric of familiarity detection. The results were consistent with letters being matched in terms of general location. Letters that were out of position that also did not maintain relativity still contributed to word recognition without identification to the same extent as letters in position. Implications for the mechanism behind feature matching are discussed.

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DEDICATION

This dissertation is dedicated to my grandfather Gary F. Wright, a one-of-a-kind gunslinger and role model. I am sorry you never got to see me become a professor, but it never would have happened without you.

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CHAPTER 1 – OVERVIEW OF THE DISSERTATION

People might use the term familiarity to describe many things, such as knowing something about a topic, or as something a person encounters on a regular basis. However, in the study of recognition memory, and in this dissertation, familiarity detection has a more specific definition. Familiarity detection is the sense that something has been encountered before without the person remembering specifics of the prior encounter. A common example is recognizing a person's face as familiar while failing to recall specifics such as who the person is or from where they are known.

Though familiarity detection has commonly been viewed as a residual or hazy, error-prone form of memory, there are a number of reasons why familiarity detection is an important topic to study. Firstly, there can be long gaps between when something is initially encountered and when it is encountered again. At times this can mean the specific details of a prior encounter are long forgotten and only familiarity detection can be used to recognize that it was encountered previously (e.g., Gardiner & Java, 1991). Secondly, familiarity detection is important to study because recalling specific details can decline with age, while familiarity detection seems to remain intact (e.g., Koen & Yonelinas, 2016). Thirdly, familiarity detection might play more of a role in false memories and false recognition compared to recalling specifics (Wixted, 2007, Wixted & Mickes, 2010), which can play a role in the current societal concern of misinformation spread (Ecker et al., 2022). Finally, and perhaps most importantly, familiarity detection might play an important role in directing the memory search for specific details (Carlaw et al., 2022; Cleary et al., 2023; McNeely-White & Cleary, 2023). If this assumption is correct, then it makes familiarity detection an important cognitive process because familiarity detection might drive attempts to recall specific details.

Although familiarity can occur with a wide-ranging variety of stimuli, it is most commonly studied in laboratory studies using word stimuli. It is mainly studied in list-learning paradigms within the overarching framework of the dual-process theory of recognition memory (e.g., Yonelinas, 2002). According to dual-process theory, there are two ways that an item on a test list can be recognized as having occurred on an earlier study list (thereby getting classified by the participant as “old” or “studied”): Familiarity and recollection. Familiarity-based recognition occurs when the test item produces a mere feeling of recognition, whereas recollection-based recognition occurs when the test item prompts a conscious calling to mind of the item’s previous occurrence on the list. A challenge for researchers taking this approach has been attempting to separate instances of familiarity-based from recollection-based recognition. One means of doing so, described below, is separating instances of recognition without identification from instances of recognition with identification (Cleary & Greene, 2001).

Although studying familiarity detection with words might seem like a narrow focus for examining a process that occurs for a wide range of stimuli, there is reason to suspect that familiarity detection with words has broader implications beyond just dual-process theory in list-learning studies. If the aforementioned assumption that familiarity detection drives memory search is correct (e.g., Cleary et al., 2023), then familiarity detection with words may be a factor driving word retrieval and identification during word reading. If so, familiarity detection may be an important behind-the-scenes mechanism within word reading itself.

There are likely many factors involved in producing word familiarity, including semantic features (Cleary et al., 2016; McNeely-White et al., 2022), but one significant contributor to word familiarity is thought to be overlapping letters between a studied word and a potentially familiar seeming word (e.g., Cleary, 2004; Cleary & Greene, 2000; Peynircioglu, 1990). This is known from use of the list learning approach to studying recognition without identification (Cleary & Greene, 2000; Peynircioglu, 1990). In this procedure, participants study a list of words (e.g., RAINDROP, AMETHYST, etc.), then they see a series of word fragments, half of which came from studied words (e.g., R_ _ ND_ _P) and half of which came from unstudied words. For each fragment presented on the test, participants are asked to try to identify the word from the fragment, and give it a feeling-of-recognition rating using a scale of 0 to 10, where 0 means no sense of recognition for the fragment in relation to the study list, and 10 means a strong sense of recognition for the fragment. Recognition without identification is the finding that, among the fragments that participants are unable to identify, participants still give significantly higher feeling-of-recognition ratings to those coming from studied words than to those coming from unstudied words. This finding is thought to be a metric of familiarity detection without recalling specifics (Cleary & Greene, 2001), as will be discussed further in Chapter 2.

Past research using this recognition without identification phenomenon to study familiarity detection (e.g., Cleary & Greene, 2000, 2001) has, at least implicitly, taken what is commonly referred to in the psycholinguistics literature as a slot specific approach to letter matching (e.g., McClelland & Rumelhart, 1981; Rumelhart & McClelland, 1982, Coltheart et al., 1993; Coltheart et al., 2001; Zorzi et al., 1998). This means that the letter matching process that is assumed to produce word recognition without identification is thought to only occur when the match occurs between letters in the same location between study and later encounter. In the above example, the R in both the studied word (RAINDROP) and the unidentified test fragment (R_ _ ND_ _ P) are the initial letter and would produce a match. If the letter R was in a different position (e.g., the second position), it would not produce a feature match for that letter in that location; thus, it would not contribute to the detection of familiarity.

However, a variety of findings on reading and lexical access open up the possibility that letter matching in the production of a word's familiarity is not a slot specific process. For example, one theory from literature on psycholinguistics and reading is that letters are coded in terms of their relative positions to one another (e.g., Peressotti & Grainger, 1999; Grainger et al., 2006). Another theory of reading is that relative position does not matter; instead, according to overlap models, letters just need to be *near* their proper location (e.g., Chambers, 1979; Andrews, 1996; Perea & Lupker, 2003a, 2003b; Gomez et al., 2008) for lexical activation to occur. Indeed, a recent study suggests that the aforementioned metric of familiarity detection, word recognition without identification, is not easily explained by the slot-specific mechanism. Specifically, first and last letters were found to make a stronger contribution to recognition without identification than internal letter positions, suggesting that particular letter positions do not contribute equally to the word recognition without identification phenomenon as a slot specific model would predict (Huebert & Cleary, 2022).

In this dissertation, I investigated which of the three aforementioned approaches (the slot specific models, the relative position models, or the overlap model approach) best applies to the letter matching process that produces familiarity as measured by the word recognition without identification effect. In the first section I discuss the recognition memory literature and the list learning approach to the study of familiarity. I also discuss how the recognition without identification effect is a metric of familiarity detection and can be used to isolate the contribution of letter features to familiarity. I then discuss how this letter matching process has primarily previously been considered as a slot specific process. In the next section, I discuss the three main approaches to how letter position has been thought to be coded in reading. In the next section, I explain the experiments conducted and review the case to be made for each of the three approaches to letter matching that can produce word familiarity. I then report the methodology and results from the two experiments before turning to the implications for letter matching as well as other types of feature matching. Finally, I discuss future directions that might establish a more comprehensive model of letter matching, and the utility of a more flexible feature matching process in accounting for word familiarity processes and how they might operate within other aspects of word processing.

CHAPTER 2 - THE RECOGNITION MEMORY LITERATURE: FROM LETTER FEATURES TO WORD FAMILIARITY

As mentioned, familiarity detection is the sense that something has been encountered before despite being unable to recall specifics of the encounter (Yonelinas, 2002). A common example is the butcher on the bus phenomenon (Mandler, 2008; MacLeod, 2020; Brown, 2020). In this situation, a person encounters their butcher on the bus who feels very familiar, yet the person is unable to recall any specifics like who the unknown butcher is, where they were encountered, or why they feel so familiar. The feeling of familiarity is thought to be different from feelings of recollection, where a person can successfully recall details of a prior encounter. To clarify, both bases of recognition involve realizing that the stimulus has been encountered before. Recalling specifics could even start out as a feeling of familiarity that later results in recalling specifics (Cleary et al., 2023). However, the focus of this dissertation will be on familiarity detection that does not end up as recalling specifics; the focus here is on familiarity judgments given in instances in which identification of specifics fails. The benefits and limitations of this approach will be revisited in the Limitations section of the General Discussion.

One major cause of familiarity detection in the absence of recall is thought to be a feature matching process (e.g., Clark & Gronlund, 1996; Hintzman, 1988; McNeely-White, et al., 2021; McNeely-White et al., 2022). There can be many other contributors to familiarity with a whole word (e.g., Cleary et al., 2016; McNeely-White et al., 2022), but the focus here will be on the contribution of letters. When a stimulus is studied or encountered, the features of that stimulus will be encoded into memory. Later on, when a stimulus is presented or encountered, it will have features too. The features of the later encountered stimulus are matched with the features stored in memory. This feature matching produces a familiarity signal that ranges in strength from lesser to greater. The general assumption is that the higher the degree of feature overlap between the features stored in memory and the features of a test stimulus, the greater the sense of familiarity. If a test stimulus has low feature overlap with features stored in memory, then a weak familiarity signal will be produced. In contrast, if the test stimulus has a high number of features that match the features stored in memory, a strong familiarity signal will be generated. This can all occur without any recollection of specific details.

This feature matching process can lead to familiarity detection with a number of different types of stimuli. This includes printed words (Cleary & Greene, 2000), spoken words (Cleary et al., 2007), music (Kostic & Cleary, 2009; McNeely-White et al., 2021), faces (Cleary & Specker, 2007; Carlaw et al., 2022), pictures (Cleary et al., 2004), scenes (Cleary & Reyes, 2009), odors (Cleary et al., 2010), and even semantic information (Cleary et al., 2016; McNeely-White et al., 2022).

The relevant features needed to produce a familiarity signal depends on the type of stimulus in question. While several word features can contribute to word familiarity, one particularly important feature is letters. This has been nicely demonstrated with several paradigms. One aforementioned method is the recognition without identification procedure (Peynircioğlu, 1990; Cleary & Greene, 2000). In this procedure, a participant studies a series of words. Next, they are shown word fragments one at a time. For example, they might study the word VOLCANIC, and later be shown the fragments VO_ _ _ _IC and RA_ _ _ _OP, in the test phase. A participant tries to identify the fragmented words, which in the above examples would be VOLCANIC and RAINDROP, respectively. Regardless of whether the word is identified or not, the participant gives a zero to ten rating as to how strongly they feel they studied a word corresponding to the fragment.

The main focus is on trials where participants cannot identify the word corresponding to the fragment. During these trials, participants still give higher recognition ratings to fragments of studied words than to fragments that do not correspond to a studied word. In the above example, participants would give higher recognition ratings to VO_ _ _ _IC than RA_ _ _ _OP. This is because although VOLCANIC was not identified during the test phase, it still contains more feature overlap, more specifically letter overlap, with a studied word. Since familiarity detection can be driven by matching features between what was studied and the test item, a stronger familiarity signal should emerge for VO_ _ _ _IC than RA_ _ _ _OP, even when neither word can be identified from the fragment.

The recognition without identification effect has been consistently replicated under many circumstances. Early studies on recognition without identification (Peynircioğlu, 1990) had participants give a rating after attempting to identify the study word from the fragment. Participants got a chance at the end of the experiment to identify words from the test fragments. Cleary and Greene (2000) noted a potential issue with this approach. Participants could have failed to identify a word initially, then identified it while making the recognition rating. Peynircioğlu did give participants a chance at the end of the experiment to identify the words. However, Cleary and Greene noted that participants could have failed to initially identify a word, identified it as they were giving the recognition rating, then forgotten it by the end of the experiment. To address this potential issue, Cleary and Greene started by doing one experiment where participants got a second chance to identify the words from fragments after making their recognition rating. The standard recognition without identification effect was still found.

Cleary and Greene (2000) also replicated the recognition without identification effect under many other circumstances. In one experiment the fragments did not contain the first letter of the target word. This meant that participants could not use a strategy of memorizing the first letter from each word. Once again, a recognition without identification effect was found. The authors also found a recognition without identification effect when the case of the letters was changed from study to test. Specifically, participants studied words presented in upper case, while fragments in the test blocks were presented in lower case, and again a recognition without identification effect was found. The authors also found a recognition without identification effect using longer study and test lists. The authors also found a recognition without identification effect when fragments were studied, and complete words appeared at test. Cleary and Greene also found a recognition without identification effect when words were read to participants at study, and printed fragments were presented at test.

Cleary and Greene (2001) also argued that the recognition without identification effect involves familiarity detection, as opposed to the recall of specifics. When the word corresponding to a fragment is not identified, there is nothing specific to recall. However, the person can still get a sense of familiarity with the fragment that is not tied to the recall of specific details. The suggestion that recognition without identification reflects familiarity in the absence of recalling specifics is also well supported. As discussed by Cleary and Greene, discriminating between studied and unstudied stimuli can rely mostly on familiarity detection (see Hintzman & Curran, 1994; Hintzman et al., 1992; Hintzman & Hartry, 1990). That is not to say recalling specifics cannot be used as well, just that distinguishing between studied and unstudied stimuli can be done with familiarity detection on its own. In contrast, recalling specifics is often required for tasks such as associative recognition or list discrimination (see Clark et al., 1993; Hintzman et al., 1998; Jacoby, 1991; Yonelinas, 1997). In associative recognition, a person must distinguish whether two words were studied together or not. In list discrimination, a person must distinguish from which list a stimulus was studied. Cleary and Greene first had participants study two words at a time. In the test blocks, participants were shown a single fragment at a time, and asked if each fragment was studied with a certain word. This again tends to rely on the recall of specifics because a person must retrieve specifics of the prior encounter, including what other word the presented word was studied with. In another condition, participants performed the standard recognition without identification procedure discussed earlier.

Cleary and Greene (2001) found that even when identification failed, participants still showed the ability to distinguish between studied and unstudied fragments. However, when identification failed, participants did not show any associative recognition, meaning that they could not distinguish which fragment was studied with which paired word. In another experiment, Cleary and Greene asked participants to distinguish whether fragments were studied in the first half of the study list or the second half of the study list. This also requires recalling specifics more than familiarity detection because a person must think back and recall the context of when the word was studied. When identification failed, participants were not able to distinguish between fragments from the first and second half of each study list. Thus, recognition without identification seems to be a product of familiarity detection and not recalling specifics.

Furthermore, the word fragment recognition without identification paradigm is thought to reflect the matching of letter features, as opposed to semantic information. For example, Cleary (2002) had participants study words and manipulated the method of encoding. Participants in one condition rated the pleasantness of words. In another condition participants counted both the number of ascending and descending letters in a given word. Ascending refers to the number of letters that go from later in the alphabet to earlier in the alphabet. For example, if the word was SHARK, participants should respond with three, since S comes after H, and H comes after A in the alphabet. Descending refers to counting the number of letters that go from earlier in the alphabet to later in the alphabet. Thus, if the study word was SHARK, the participant should respond with two, since A comes before R. Participants were then shown word fragments during the test blocks.

Cleary (2002) found that rating pleasantness resulted in higher identification rates compared to counting ascending or descending letters. Participants were also more confident that an identified word fragment corresponded to a study word if they had made a pleasantness rating, compared to if they made ascending and descending counts. In contrast, there was no effect of encoding condition on recognition ratings for unidentified fragments. Cleary also confirmed these results using other encoding manipulations, such as self-relevance ratings compared to counting the vowels within a word. The type of encoding did affect both identification rates, and recognition *with* identification, but not recognition without identification. From these results, Cleary suggested that recognition *with* identification might involve the use of meaning, given that more meaning oriented encoding methods increased the magnitude of recognition with identification. In contrast, recognition without identification seems to result from letter overlap, given that meaning oriented encoding did not affect it.

In the third and fourth experiments Cleary (2002) had participants enter a word after being given a definition or type the word after being given the word in reverse. Cleary found that having to generate the word in either way, actually increased recognition without identification. That is, participants gave higher recognition ratings to unidentified fragments when their corresponding word had been generated, as opposed to their corresponding word having been read. Taken together, these results suggest that familiarity detection in the recognition without identification method is being generated using a letter matching process, rather than the meaning of words. If the meaning of words was the feature responsible for familiarity detection, then one would expect familiarity to increase when participants paid more attention to the meaning behind each word. They would have paid more attention to the meaning when providing pleasantness ratings or self-relevance ratings. In contrast, generating words would have required more attention to the letter information of the words. Since generating words produced a bigger recognition without identification effect, this suggests that recognition without identification is driven by letter information. This also means that the word fragment recognition without identification effect is ideal for examining letter-based familiarity production.

Another method that has been used to suggest the contribution of letters to word familiarity is the Recognition Without Cued Recall paradigm (Cleary, 2004; Ryals & Cleary, 2012; Huebert et al., 2022). In one variant of this procedure, participants study words (e.g., CHEETOH). They are then shown cue words at test, some of which resemble studied words (e.g., CHEETAH), and some of which do not resemble studied words (e.g., LAUGHED). Participants first rate how strongly they feel the cue resembles a studied word. Next, participants try to recall the studied word resembling the cue, assuming there was one. Of particular interest are the familiarity ratings given when cued recall fails, similar to how recognition without identification is mainly about recognition that occurs without the identification of the full word. For recognition without cued recall, this would be when a participant sees CHEETAH and does not recall the word CHEETOH. In these instances, participants will still give higher familiarity ratings to cues resembling study words than to cues that do not resemble studied words. This presumably occurs for the same reason that the recognition without identification effect occurs (Cleary & Greene, 2000). Although the studied word resembling the cue cannot be recalled, the cue might still feel familiar if it has feature overlap with a studied word, at least more so than when a cue does not resemble a studied word. In four experiments, Cleary was able to identify several features that can contribute to familiarity detection, including orthography, phonology, and semantics. However, the first experiment suggested that letters can be one key feature leading to word familiarity.

Additionally, Ryals and Cleary (2012) have suggested that letter features seem to play a role in word familiarity. Participants studied words high or low in concreteness. At test, participants were shown non-word test cues. Some of the test cues resembled studied words while some did not. Ryals and Cleary found a dissociation where the concreteness of the target words did affect both cued recall and recognition ratings when cued recall succeeded. However, recognition without cued recall was not affected by word concreteness. The same pattern was also found when manipulating study word emotionality. The authors argued that feature matching between a test cue and a studied word can only occur between the features stored in memory and the features that are present in the test cue. Since both the concreteness and emotionality of the studied words was not present in the cues themselves during recall failure, these features could not be matched from the cue to memory representations to influence the familiarity signal that was theorized to be at work. Thus, these variables did not affect recognition ratings during cued recall failure. Only the features present in the cue itself could be used to generate cue familiarity.

Ryals and Cleary (2012) ran an additional experiment further demonstrating dissociations between recognition with and without cued recall. The authors showed participants a mix of study words, such as PITCHFORK, PULLCORK, POCKETBOOK, PATCHWORK, and TRANSPARENT. In the test blocks participants were shown non-word test cues. The feature overlap between test cues and study words was manipulated. Some test cues resembled four study words such as POTCHBORK, while some test cues only resembled one studied word, such as TRENSORENT. As in prior work (Cleary, 2004), some test cues did not resemble any studied words, such as ARBLE. The authors found that during recall failure, test cue familiarity increased with feature overlap. Specifically, test cues that resembled four study words felt the most familiar, followed by test cues that resembled one study word, followed by test cues that resembled no study words. This manipulation also had an effect during recall success, but it was a smaller effect in comparison to when recall failed. This result also suggests that letter overlap is a significant factor in driving word familiarity. This is because as letter overlap between studied words and test cues increased systematically, so did feelings of familiarity.

It is important to note that although the studies discussed so far demonstrate the role of letters as one feature that can contribute to word familiarity, letters contain both orthography and phonology. Orthography is the visual shape of the letters, while phonology is the sound the letters produce. People tend to sound out words in their heads even when told to read silently, possibly playing a role in word identification (see Leinenger, 2014 for a review). There is also evidence that this phonology plays a role in word familiarity. As mentioned earlier, Cleary and Greene (2000) did one experiment where participants listened to spoken words at study, and then fragments were presented on a computer screen at test. Using this methodology, the standard recognition without identification effect was found. Additionally, Cleary (2004) did one experiment where participants listened to words at study and were presented with words visually at test. Furthermore, Cleary did another experiment where study words and test words had similar sound despite having different orthography (e.g., RAFT and LAUGHED). In both of these experiments, Cleary found that the effect size of familiarity ratings during recall failure was larger compared to when both orthography and phonology overlapped (e.g., CHEETAH and CHEETOH). Taken together these results suggest that although the orthography from letters contributes to word familiarity, phonology also plays a role. However, the point of this dissertation is not to separate the contribution of orthography and phonology to word familiarity, thus I use the neutral term letters, which can encapsulate both orthography and phonology.

All of the experiments establishing the contribution of letters to word familiarity discussed above have taken one specific approach to letter position matching. This approach is that the overlapping letters between study and test were also in the same location between study and test. In the recognition without identification studies discussed (e.g., Cleary & Greene, 2000), words and test fragments would always be in the same location between study and test. The same was mostly the case for the recognition without cued recall studies discussed (Cleary, 2004; Ryals & Cleary, 2012). For example, when PITCHFORK was studied, the letters of the test cue POTCHBORK that do overlap with PITCHFORK are in the same location between the studied word and test cue. There were some study and test cues that had an unequal number of letters. For example, the word SPAGHETTI might be studied, and the test cue might be SPURGONI. However, Ryals and Cleary did not separately analyze study words and test cues that had matching letters in the same locations versus different locations. In fact, there were likely not enough trials for any meaningful comparisons to be made regarding this question. Other than Ryals and Cleary having some of the study and test items that did not match up perfectly, the issue of to what extent letter position matching matters with regard to word familiarity has not been explored. An unexplored question is whether a slot specific approach is a requirement for the letter matching process that is theorized to produce word familiarity. In the next section, I discuss the slot specific assumption. Following that, I discuss studies that speak against the slot specific assumption.

CHAPTER 3 – THE PSYCHOLINGUISTICS LITERATURE: THEORIES OF LETTER POSITION REPRESENTATION

Slot Specific Coding in Lexical Activation

Older models of reading assumed a slot specific approach to reading words. The slot specific assumption is that letters only contribute to word processing when they are in the correct position. This is most evident from the interactive activation model of reading (McClelland & Rumelhart, 1981; Rumelhart & McClelland, 1982). When a person successfully identifies a word, this occurs partially through letter matching. The letters of a word are identified, which in turn activates potential words that contain those letters in those positions. For example, if the letter A is in the first letter position of a four-letter string, then words such as ABLE, ACTS, ALSO, and other words starting with A would be activated. Furthermore, the letter A seen in the first position will also inhibit words without an A in the first position. The same will occur for all letter positions. However, when it comes to letter position coding, Mclelland and Rumelhart took a slot specific approach. This means that the letters of a word being read will only activate words in the lexicon that contain those letters in the same location. For example, when the letter A is detected in the first position, it will again activate words that have A in the first position, such as ABLE. However, under the slot specific assumption, when the letter A is detected in the first position, it will not cause activation of words that have A in the second or third position, such as PART or FLAT.

Another seminal model of reading is the Dual Route Cascade Model (Coltheart et al., 1993; Coltheart et al., 2001). According to this model, there are two routes to reading. One is the direct route, and the other is the indirect route. The direct route is typically used for higher frequency words, while the indirect route is typically used for lower frequency or novel words. The two routes differ in a number of ways. When it comes to phonology, or processing the sound of words, the direct route is thought to retrieve phonology from memory, instead of constructing the phonology from the letters. This is because the word has been encountered enough that phonology can be quickly retrieved. In contrast, when a word is read through the indirect route, the phonology must instead be assembled. There is not a strong enough representation of the word, and a person must use the graphemes of the word to sound it out from left to right (Coltheart & Rastle, 1994).

Since the indirect route requires the person to assemble phonology, this means the indirect route is slower than the direct route. The indirect route also involves reading from left to right, while the direct route involves parallel processing of all letters, though first and last letters might be processed slightly faster (e.g., Jordan et al., 2003). However, most important to the current investigation, the Dual Route Cascade Model makes the same slot specific assumption of letter position coding.

There is also the Parallel Distributed Model of reading (Zeigler et al. 1998). This model has different ways of handling a number of issues in reading compared with the other models discussed so far. This is especially true with regard to pronouncing words with irregular letter to phoneme relations (e.g., PINT). However, this model, just like the others discussed so far, also makes the same slot specific assumption.

Taken together, these models represent invaluable ways to simulate and test many theories and assumptions about reading words. However, they all assume that activation occurs in a slot specific way. Letters that are not in the correct position do not contribute to lexical activation that leads to a word's access. Letters only matter when they are in the correct slots. However, as I discuss in the next two sections, letter position coding in the human mind is not so simple.

Relative Position Coding in Lexical Activation

A number of findings on priming and lexical decision contradict the slot specific assumption. In a priming and lexical decision task, a participant is typically shown a fixation point on a computer screen. A prime is then presented for a very short time, not nearly long enough for a person to identify the prime. The prime is then followed by a mask, typically a string of symbols (e.g., %%%%). The mask is then followed by a target, either a word or a non-word. The participant must classify the target as a word or non-word as quickly as possible. Typically, the non-words just act as filler, and the real interest is in the lexical decision speed for actual words. The prime will partially activate the target word in question. Various factors of the prime can be manipulated to examine the effect on lexical decision speed. The logic is that the more the prime decreases lexical decision times for words, the more the features of that prime are significant in activating a word. For example, a prime could contain either the interior letters or exterior letters of a target word. Priming with exterior letters decreases lexical decision time more so than priming with interior letters. This suggests that exterior letters are more important than interior letters in reading words (e.g., Jordan et al., 2003).

A number of findings using priming and lexical decision have been used to argue against the slot specific assumption of reading. Instead of the slot specific assumption, others have argued in favor of a relative position coding scheme. This theory of letter position coding suggests that letters are coded in relation to one another (Peressotti & Grainger, 1999). For example, in the word TRUCK, the letter R is coded as being after the letter T and before the letter U. This is different from the slot specific assumption where the letter R would simply be coded as being in the second position.

To test the relative position coding theory, Peressotti and Grainger (1999) gave participants six letter French words. These words were either primed with four letters from the target, or four letters plus two letters not present in the target. For example, if the target was BALCON, the prime would either be BLCN, or BSLCRN. From a slot specific theory, the four-letter primes should not increase lexical access speed because they do not overlap one to one with the targets. Only the six-letter primes do overlap one to one with the target and should thus produce priming effects. However, the four-letter primes do contain the same relative position coding as the targets, which could produce the priming effect. Peressotti and Grainger did not find that the six-letter primes reduced lexical decision time any more than the four-letter primes. This is difficult to explain from a slot specific theory because the four-letter primes did not have letters in the same slots as the target.

Peressotti and Grainger (1999) noted that the six-letter primes could have produced no difference in priming from the four-letter primes because the six letter primes also contained two letters that were not present in the target. In the above example, BLCN shares four letters with the target BALCON. The prime BSLCRN contains four letters of the target as well, but it also contains two letters that are not present in the target. The non-matching letters from the six letter primes could have increased lexical decision time for targets. To address this issue, the authors ran another experiment. This time, either four letter primes, or four-letter primes with additional symbols were used. For example, if the target was BALCON, the prime could be either BLCN or B%LC%N. The logic here was that the addition of symbols makes the letters in the prime line up perfectly with the letters of the target. From a slot specific approach, this should produce priming. In contrast, if relative position is what matters, then BLCN should produce the same amount of priming as B%LC%N. The authors found the second possibility to be the case, suggesting that letter positions are coded relative to each other, rather than in slot specific positions.

Peressotti and Grainger (1999) also ran an experiment where the prime either contained the same relative positions of letters or disrupted the relative positions with the target. For example, if the target was BALCON it would either be primed with NLCB or BLCN. The logic here was that both prime types contain four letters from the target, but only the latter contains the same relative letter positions as the target. Indeed, the authors found that primes containing the same relative positions of letters as the targets such as BLCN produced significant priming. In contrast, primes that did not maintain the same relative positions of letters with targets, such as NLCB did not produce any priming. This again suggests that letters are coded in terms of their positions relative to one another.

Grainger et al. (2006) would also find further evidence for the relative position theory of letter coding. Additionally, the authors investigated the issue of relative position coding with respect to seven letter words, since Peressotti & Grainger (1999) only used six letter target words. In one condition, the prime contained only five of the seven target word letters, and replaced the missing letters with dash marks. For example, if the target was ACADEMY, the prime would be A-ADE-Y. According to the slot specific approach, this condition should produce the most priming because letters are coded in terms of their absolute slots. In another condition, the prime contained the same letters, but only in terms of relative position and not absolute position. For example, the prime for ACADEMY would be AA-D-EY. For these primes, some of the letters were now out of the correct slots, but still maintained the correct relative position, such as the second A appearing after the first A, but before the D. Grainger et al. found that the two prime types produced equivalent priming effects, despite only one maintaining the correct absolute slot positions.

However, in another experiment, Grainger et al. (2006) gave participants primes without relative position intact. For example, if the target was ACADEMY, the prime could be Y-ADE-A. These types of primes did not reduce lexical decision times. This suggests that relative position must be maintained for lexical access to occur. Grainger et al. also investigated whether relative position coding is specific to certain letter positions and found that maintaining relative position produced significant priming across all letter positions. Finally, Grainger et al. found these results to be generalizable to nine letter words as well.

Overlap Position Coding in Lexical Activation

Despite the research discussed so far suggesting that letter position is coded in terms of relativity, other researchers have argued differently (e.g., Chambers, 1979; Andrews, 1996; Perea & Lupker, 2003a, 2003b; Gomez et al., 2008). Specifically, letters also activate words that share those letters even if they are out of position, and do not maintain relative positions. For example, if the letter E is in the third position, it will activate words that contain the letter E in the third position. However, the letter E will also activate words that have the letter E in other positions as well, just to a lesser degree. I will refer to these as overlap effects.

Overlap effects were initially demonstrated without the use of priming. Chambers (1979) gave participants words where transposing letters would make other words. For example, SLAT is a word and is also a transposition of SALT. Participants took longer to identify these transposed target words than regular words that could not be transposed into other words. Andrews (1996) would replicate these findings and argue that letters also activate adjacent positions and not just their own positions. This means that SLAT would cause some activation of the word SALT. Andrews argued that since two words are competing for activation, the decision takes longer. Participants in both studies were also given non-words that were transposed versions of existing words, such as STROE, which is transposed from STORE. Participants took longer to classify items like STROE as non-words than other types of legal non-words. Andrews again suggested that letters will cause some activation of adjacent letter positions, this results in STROE causing some activation of STORE. The activation of STORE means it takes longer to realize STROE is not a word.

Priming and lexical decision experiments have also provided a great deal of support for overlap theories of letter position coding. Perea and Lupker (2003a) compared the effect of what they called Transposed Letter (TL) primes to orthographic controls. The TL primes contained the same letters as the targets, but in the wrong positions. For example, if the target word was USHER, the TL prime could be UHSER, while the orthographic control would be

UFNER. According to a slot specific account of reading, there should be no difference in lexical decision time between the TL prime and the orthographic control prime. This is because although the TL prime has more overlapping letters with the target word than the control prime, the letters are out of position. Under a slot specific model letters cause activation with words sharing those letters in their position and their position only. Thus, TL primes should not produce any more priming than control primes where the out of position letters are replaced. However, according to an overlap approach, letters will cause activation in their position, but also in the adjacent positions, just to a lesser degree. Perea and Lupker found that TL primes caused more of a decrease in lexical decision time than did control primes, supporting the overlap approach.

Perea and Lupker (2003a) also compared the TL primes to identity primes, which are identical to the target words. Though the TL primes produced more priming than replacement primes, they did not produce as much priming as the identity primes. This suggests that although letters out of place cause activation, they do not cause as much activation as when they are in the correct positions. In further experiments, the authors also found that these overlap effects were partially sensitive to positions. Specifically, a transposition occurring at the last letter position did not show the same amount of priming as did a transposition at the interior positions. The authors did not examine the first letter position.

The nature of letter transpositions is also not just specific to the sub lexical level. Letters that are out of position also cause activation of the actual meaning behind the words, or the lexical features. Perea and Lupker (2003b) have investigated this issue. The authors presented participants with a mix of identity primes, transposition primes, and replacement primes.

Identity primes were normal words related to the target. For example, if the target was COURT, the identity prime would-be JUDGE. The transposition primes would be the same as identity primes, but with two internal letters transposed, such as JUGDE. Finally, the replacement primes would be similar to identity primes, except those two internal letters were replaced (e.g., JUPFE). The logic here is the same as the study discussed above. If letter position is coded in a slot specific manner, or in terms of relativity, then primes like JUGDE should not produce any more priming than primes like JUPFE should. However, the authors found that primes like JUGDE produced more priming than primes like JUPFE. This suggests that letters out of position can cause activation of the meaning of words that contain those letters. These results also suggest that letter position is not coded in terms of relativity either. This is because the transposition primes did not maintain the relative position of letters any more than the replacement primes did.

As in prior work (Perea & Lupker, 2003a), Perea and Lupker (2003b) found that identity primes still caused more priming than did transposition primes. This again suggests that letters cause activation when out of position, but to a smaller degree. In subsequent experiments the authors examined whether these effects were specific to internal letters. Thus, in other experiments they ran the same design except that the transpositions or replacements occurred for the second last and last letter positions. This produced no significant priming effects. The authors did not examine the first letter position.

The issue of overlap coding has also been demonstrated in the context of sentence reading. Rayner et al. (2007) gave participants sentences such as “The boy could not solve the problem so he asked for help” pp 292. In these sentences, some of the words contained a transposition of letters. For example, “The boy cuold not slove the probelm so he aksed for help” pp 292. These particular types of letter transpositions did slow down reading, but only by 11 percent compared to a control with no transpositions. This is especially striking considering that across all of the stimuli, 40 percent of the words contained a transposition in the transposition conditions. This suggests that although letters still cause activation if they are out of place, they do not cause the same level of activation as when they are in the correct location, and there is a cost to letter transpositions.

It is worth noting that some letter positions are more sensitive to transpositions compared to others. Specifically, the first letter and last letter positions are not as tolerant of transpositions as any of the interior positions. Indeed, Rayner et al. (2007) found that first letter transpositions slowed down reading more so than transpositions at any other letter positions. Additionally, letter transpositions occurring at the last letter position slowed down reading more than interior letter transpositions. As discussed earlier, priming and lexical decision studies (Perea & Lupker, 2003a, 2003b) have also shown that the last letter position is not as tolerant of transpositions compared to interior positions.

Considering all of these results, Gomez et al. (2008) have proposed a computational model to account for letter position coding. According to this model, letter positions are best characterized as a series of bell curves (see Figure 1). For example, if the letter I in TRAIL appears in the fourth letter position, it will cause the strongest activation for words that have the letter I in the fourth position. However, the letter I will still activate words that contain the letter I in the third and fifth position, such as TRIAL, just to a lesser degree. The letter I in the fourth position will also activate words with the letter I in the second position, but to an even smaller degree. Overall, letters will activate words that share those letters, even if out of position. The further away from the correct position the letter is, the less activation it will cause.

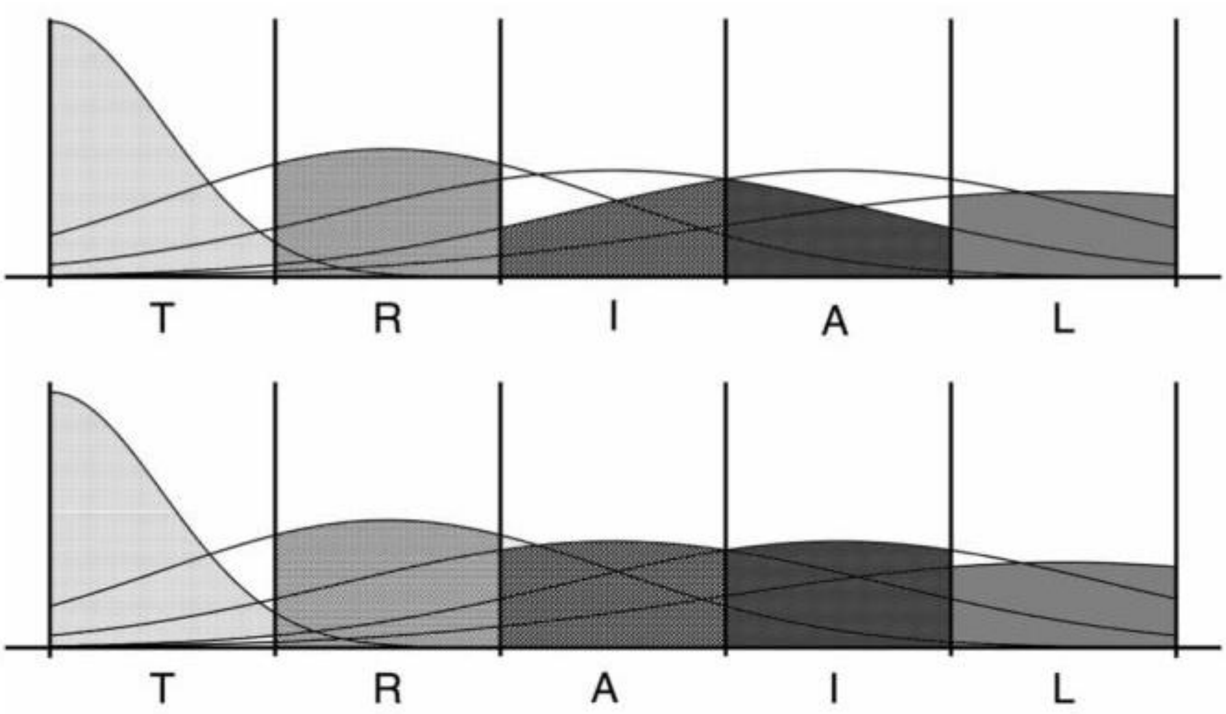

Figure 1. An illustration of the overlap model take from Gomez et al. (2008).

CHAPTER 4 – THE CURRENT EXPERIMENTS

To briefly summarize, research on reading and word identification has suggested three main ways in which letter positions may be coded. The earliest is the slot specific assumption, where letters only activate words that share those same letters in those same locations (e.g., McClelland & Rumelhart, 1981; Rumelhart & McClelland, 1982; Coltheart et al., 1993; Coltheart et al., 2001; Zorzi et al., 1998). Another theory is that letter position is coded in terms of relativity to other letters (e.g., Peressotti & Grainger, 1999; Grainger et al., 2006). The other major theory is that letters are coded in an overlapping manner, meaning that letters cause activation even if they are out of position (Chambers, 1979; Andrews, 1996; Perea & Lupker, 2003a, 2003b; Rayner et al., 2007; Gomez et al., 2008). The letters might still need to be near their correct locations though. Furthermore, letters that are out of position will cause less activation compared to letters in the correct slots.

As discussed earlier, research suggests that word familiarity can be driven by overlapping letters between what has been stored in memory, and a current test word or fragment. However, investigations into word familiarity have primarily thus far considered the slot specific assumption. For example, studies by Cleary and Greene (2000), or Cleary (2002), or Huebert and Cleary (2022) all have something in common. All of these studies had participants study words, and then at test the matching word fragments would have letters in the same locations as they were studied. Even in Huebert and Cleary's study of whether certain letter positions (namely, the first and last letter position) matter more to the word recognition without identification effect than other positions (i.e., internal positions), the test fragments still maintained letters in their original positions as the target word. The same was also true for when participants studied word fragments and were given words at test in Cleary and Greene's (2000) study. Finally, the same was mostly true for the recognition without cued recall experiments discussed earlier (Cleary, 2004; Ryals & Cleary, 2012). Some of the study words had unequal numbers of overlapping letters with test cues, but this was not systematically investigated.

This all begs the question: How is letter position processed with regard to the letter feature matching process that is theorized to contribute to word familiarity? Do letters need to be in the same slots between study and test for the matching process to work? Based on what we know about letter position coding in reading, the letter matching process might not be so simple. It could instead be the case that much like word activation, overlap between letters, even if out of position, still contributes to the familiarity signal theorized to be used in word recognition without identification. One possibility is that the letter matching process occurs in terms of relativity. If this is the case, then there only needs to be a relative position match between study and test. Another possibility is that the letter matching process occurs in a more flexible manner. If this is the case, then letters that are out of both absolute and relative position can still contribute to a familiarity signal. The question of how letter location works with regard to word familiarity has not been explored. Thus, it is useful in terms of understanding how this process works.

This research also has theoretical and potential practical implications with regard to false memories for words. Previous research using what is known as the false memory paradigm has shown that when people study a list of orthographically similar associates (e.g., cape, tape, ripe, part, perk, dark), they are more likely to falsely recognize an unstudied orthographically similar lure (e.g., park) than if the similar associates had not been studied (Pesta et al., 2001). This raises the question: If a person was to read a name such as RANDY, what kind of names could be wrongly recognized in place of RANDY? From the slot specific approach, a person might only falsely recognize a name such as MANDY. This is because RANDY and MANDY have four overlapping letters in the same slots. However, if the relative position approach is correct, then there are many other names that could be wrongly recognized. Names such as ANDY or BRANDY could be recognized in place of RANDY. This is because although ANDY and BRANDY do not have letters in the exact same slots as RANDY, they do have letters in the same relative positions. In contrast, if the overlap approach is correct, then DANY could be mistaken for RANDY. The letter Y in the final position could contribute to this false recognition, however, the other letters A, D and N could contribute as well. Those letters do not share the same slots between the two names, but if there is flexibility to the letter matching process, they could still contribute to the familiarity signal that would presumably underlie false recognition.

This research is also important from the perspective of reading and word identification. The issues of letter position coding have really only been investigated with regard to reading speed and word identification speed (e.g., Rayner et al., 2007). Very little is known about how these issues operate with respect to long term memory. Furthermore, are the issues of relative position coding, or overlap coding specific to relatively fast cognitive processes like reading? Or do they play a bigger role in cognition, such as how we remember and recognize words from their letter features? Finally, as suggested earlier, familiarity detection may be a behind-the-scenes mechanism that serves to drive attention inward toward memory retrieval effort (Cleary et al., 2023); if so, then it may be a central process behind both long-term memory retrieval and basic abilities such as word reading.

To investigate the question of how letter position matching might occur with regard to word familiarity, I used the following general methodology, which is a variant of the aforementioned word recognition without identification paradigm. Participants started by studying a list of words as is typical in experiments on recognition memory, including recognition without identification (Cleary & Greene, 2000). Participants were then presented with a series of word fragments during each test block. One manipulation was whether the word fragments corresponded to a studied word or not. Participants first gave a familiarity rating of the fragment. They then attempted to solve the word fragment. As in prior work explained above, the main focus is on the familiarity ratings given to fragments that were not identified (e.g., Cleary & Greene, 2001).

The word fragment recognition without identification paradigm is ideal for examining the letter matching process that can contribute to word familiarity for a few reasons. Firstly, when focusing on trials without identification, it allows for the isolation of particular letters as the driver of familiarity detection. As discussed earlier, Cleary (2002) found strong evidence that letters are the driver of word fragment recognition without identification. Additionally, because several letters are replaced with underscores, only the letters that are presented in the fragment can be used to generate familiarity. As Ryals and Cleary (2012) demonstrate, to generate a sense of familiarity with a cue during retrieval failure, the cue itself must contain to-be-matched features that are present in the relevant memory traces (features that were studied but not present in the cue itself did not contribute to familiarity-based discrimination, and only the features present in the cue itself are available for the feature-matching process presumed to underlie familiarity-based discriminability). Thus, in addition to serving as a means of isolating familiarity from recall (see Chapter 2 and the discussion of evidence reported by Cleary and Greene, 2001, that word fragment recognition without identification reflects familiarity detection in the absence of recall), focusing on trials where participants do not identify the word should remove any effects of lexical properties that would otherwise be present in an identified word and that would potentially confound the ability to examine the questions about letter position information under investigation in the present study. For these reasons, if the participant identifies the word from the fragment, the trial would not be included; the focus here is on familiarity judgments given to word fragments that go unidentified.

Also, other lexical properties of the stimulus words (such as word frequency, age of acquisition, and imageability) are certainly important to consider with regard to word familiarity more broadly (e.g., Cortese et al., 2015), but are not the focus of this dissertation and are additionally addressed for the present purposes through counterbalancing of the stimuli across the experimental conditions of studied vs. unstudied status, and through conducting items analyses in addition to subjects analyses.

The main manipulation for the present study occurred during each of the test segments of each block. Regardless of whether the fragment corresponded to a studied word or not, there were three types of fragments. One type of fragment contained the same letters in the same locations as the normal word. For example, _AN_ _ _GO_, was a fragment of

BANDWAGON. This fragment condition is simply a replication of prior work (e.g., Cleary & Greene, 2000). The letters present in the fragment were in the same slots as they were studied, such as the A and N appearing in the second and third letter positions, and the G and O appearing in the seventh and eighth positions. These will be referred to as Slot Specific Fragments. All of the slot specific fragments had underscores in place of the missing letters as in prior work done by Cleary and Greene. The underscores in the Slot Specific Fragments also made it so that the letters in the fragment lined up with those same letters present in the studied word in a slot specific manner.

As mentioned earlier, the underscores also served another important purpose. The purpose was to isolate particular letters as the sole driver of the familiarity signal presumed to underlie familiarity-based discriminability of studied vs. unstudied status among unidentified word fragments in the recognition without identification paradigm. Based on aforementioned work suggesting that only features that are present in the cue itself can contribute to the feature-matching process theorized to underlie judgments that are strictly familiarity-based (e.g., Ryals & Cleary, 2012), since the fragments only contained a set number of letters from the target words, only those particular letters (and not extraneous features that are not contained in both the test fragment and the target word) should be able to contribute to the magnitude of the recognition without identification effect. The letters that were replaced by underscores should not have acted as a feature to be matched up with any letters stored in memory. This is also somewhat analogous to how Peressotti and Grainger (1999) replaced letters with symbols such as priming BALCON with B%LC%N. The underscores in my study should not have subtracted or added to the familiarity signal, just as how the percent symbols used by

Peressotti and Grainger should not have increased or decreased lexical activation of the target word.

The other type of fragments used in the present study also contained the same letters as studied and unstudied words. However, those letters only had the same relative positions and not the same absolute positions as the target words. In Experiment 1, this was done by shifting each of the four letters one slot toward the center. For example, the fragment for BANDWAGON was _ _AN_GO_ _. Thus, the letter overlap between study and test was there, but only in terms of the relative positions of the letters. These will be referred to as the Relative Position Fragments. Similar to the Slot Specific Fragments, missing letters were replaced with underscores. The underscores for the Relative Position Fragments meant that the letters from the target word now overlapped with an underscore, or a different letter when considering slot specific coding. In the above example, the A overlaps with an underscore in the fragment, and the N overlaps with the A in the fragment. However, the underscores do not compromise the relative position of the overlapping letters. In the example, the A still comes before the N, and the G before the O in the fragment.

In the final condition, test fragments had the same letters as the other two conditions, but without maintaining the relative positions of the study word letters. These fragments were simply the two letters of each letter pair from the Slot Specific Fragment transposed. For example, the test fragment of the word BANDWAGON was _NA_ _ _OG_. These will be referred to as the Transposition Fragments. Note that study words were not repeated across conditions, the same word for each condition is used here for clarity. As in the other two conditions the missing letters were replaced with underscores.

Importantly, both the Relative and Transposition Fragments had letters that were the same overall distance from the correct locations. In the example of the Relative Position Fragment, the letters A and N have each shifted one slot to the right. The letters G and O have each shifted one slot to the left. In the Transposition Fragments, the A and N have switched places, and the G and O have switched places. However, the A is still only one slot away from its original slot and the same is true for the other three letters. However, only the Relative Position Fragments maintained relativity from the letters of the studied word.

Furthermore, the letters that appeared during the test blocks in Experiment 1 were all from the same positions as the examples presented above. They did not contain the first letter position or last letter position. This was done because if the overlap coding approach is supported, there is reason to believe that it would not be the same for each letter position. This is because the various experiments on letter transpositions have shown that the first and last letter positions are much more sensitive to transpositions than any of the interior letter slots (Perea & Lupker, 2003a, 2003b; Rayner et al., 2007; Gomez et al., 2008), and Huebert and Cleary (2022) showed this to be true of the word fragment recognition without identification effect too. It could be the case that word familiarity does work even with transpositions, just not with the first and last letter positions, or that first and last position would interact in some way. Thus, I only focused on the interior letter positions for this dissertation. Finally, the methodology was largely the same in Experiment 2 and will be explained in more detail after Experiment 1.

There is a case to be made for a number of possible outcomes. The only somewhat certain prediction is that the Slot Specific Fragments should show the standard recognition without identification effect, in replication of the original recognition without identification studies (Peynircioglu, 1990; Cleary & Greene, 2000, 2001; Cleary, 2002; Huebert & Cleary, 2022). This means that even for fragments that are not identified, fragments that correspond to a studied word should receive higher familiarity ratings than fragments that do not correspond to a studied word. Both the fragments that correspond to studied words and the fragments that do not correspond to a studied word are really there to replicate the standard recognition without identification effect and provide a baseline for comparison. If letter matching (for interior letters) occurs in a slot specific manner, then only the Slot Specific Fragments should show a difference in familiarity ratings. There should be no difference for either of the other two fragment types.

The Case for Relative Position Coding

The main question is in regard to the Relative Position and Transposed Fragments. If the letter matching process that produces word familiarity occurs in terms of relativity, then there should be a difference in familiarity ratings between studied and unstudied fragments in the Slot Specific Condition. There should also be the same pattern with the Relative Position Fragments. There should not be such a pattern for Transposition Fragments because these fragments do not maintain the relative position of letters between study and test. This possibility mainly stems from the research suggesting that letter position is initially coded in terms of relativity. Support for this notion can be found in the studies on priming in lexical decision tasks (e.g., Peressotti & Grainger, 1999; Grainger et al., 2006). To briefly summarize, primes that maintain the relative position of letters produce significant priming. On the other hand, primes that do not maintain the relative position of the letters with the target, have been shown to not produce significant priming in these particular studies.

If letters are initially coded in terms of their relative positions, then perhaps the letter matching process that generates familiarity detection operates in a similar fashion. One could argue that reading words and generating feelings of familiarity are different processes. It could be the case that the concept of relativity only applies to the early stages of lexical access. If relative position coding only applies to lexical access and word identification, then there should only be a recognition without identification effect for the Slot Specific Fragments.

However, a number of experiments have shown striking similarities between word identification and word familiarity. The best example comes from a study by Huebert and Cleary (2022). Many experiments on priming and lexical access have suggested that the exterior letter positions carry more weight in lexical access compared to any of the interior letter positions (e.g., Jordan et al., 2003). The special significance of exterior letters has also been demonstrated in the context of sentence reading (Rayner et al., 2007; Johnson & Eisler, 2012). Huebert and Cleary found that the special significance of exterior letters also applies to feature matching and word familiarity. Using the recognition without identification method, they gave participants study fragments that contained either the exterior letters or the interior letters of the target words. Huebert and Cleary found that studying exterior letters increased familiarity ratings (and studied vs. unstudied discriminability) on later test words more so than studying interior letters. This suggests that exterior letters play more of a role in word familiarity, just like they do in reading and word identification. Furthermore, vowels and consonants seem to play different roles in word reading (New et al., 2008), with consonants being more important in lexical access. This also seems to be the case with word familiarity (Huebert et al., in progress). Thus, if reading and word familiarity have some similarities, then it is possible that the letter matching that produces word familiarity also operates in terms of relativity.

There is also support for the relative position coding approach to word familiarity from research on music familiarity. Kostic and Cleary (2009) had participants listen to well known songs during the study blocks. In one experiment, during the test blocks, participants listened to the isolated pitches from the songs. Some of the isolated pitches had the notes played in the correct order. In contrast, some had the notes scrambled. Kostic and Cleary found that even when participants could not identify songs at study, they still gave higher recognition ratings to isolated pitches corresponding to a studied song than to pitches not corresponding to an unstudied song. This was found to be the case for isolated pitches that maintained the correct order of notes. However, no difference in recognition ratings were found when the pitches had the order of the notes scrambled.

Kostic and Cleary (2009) did another experiment, where participants again listened to songs at study. During the test blocks, participants heard isolated rhythms. However, the speed of those rhythms was altered from what was studied. The authors still found a significant difference in recognition ratings between studied and unstudied rhythms, despite the speed being different from study to test. The authors suggested that music information might be coded in terms of relative position. Participants did not show a recognition without identification effect when the order of notes was scrambled between study and test, which would mean neither absolute nor relative position was maintained. In contrast, participants did show a recognition without identification effect when the tempo was changed between study and test. With tempo being changed, this would mean that the relative position of the features was maintained even if the absolute position was disrupted.

If the feature matching process that leads to music familiarity occurs in terms of the relative position of features, as opposed to the absolute position, it is entirely possible that letter matching occurs in a similar way. Perhaps in order for the letter matching process to occur, producing word familiarity, the letters of a study word and test word only need to have overlapping letters in the same relative positions. The study and test words might not need to share the same absolute or slot specific locations.

The Case for Overlap Position Coding

Although a case can be made for relative position coding, a case can also be made for overlap coding. According to Gomez et al. (2008) initial letter position information can best be described as a series of distributions (see Figure 1). This has been modeled and tested with regard to reading and identifying words. Perhaps the process of letter matching to stored letters can be thought of as being more of a range. If this is the case, then letters do not need to be in the exact same location, or the same relative location, they instead just need to be near their studied location.

The main reason to predict an overlap approach to letter position coding is the research on letter transpositions discussed previously. To briefly summarize, letters that are out of position still cause lexical activation even if they are not in the correct slots, and do not maintain relativity (Gomez et al., 2008). For example, the word USHER could be primed with either UHSER or UPFER. According to the slot specific assumption, letters that are out of position do not cause any activation of words that contain those letters in the correct position. Therefore, replacing letters should produce no more priming than transposing those letters. However, that is not what is typically found. Transposition primes produce more priming than do replacement primes (Perea & Lupker, 2003a, 2003b).

As noted earlier, lexical activation and word familiarity seem to share some properties (e.g., Huebert & Cleary, 2022). Given the similar mechanisms behind lexical access and word familiarity, it is quite plausible that word familiarity might share the same property of overlap position coding. If this is correct, both the Slot Specific and Relative Position Fragments should show a recognition without identification effect.

It is also worth noting that the results found by Kostic and Cleary (2009) do not rule out overlap coding. As discussed earlier, Kostic and Cleary found that scrambling the order of notes produced no recognition without identification effect. However, altering the tempo still produced a recognition without identification effect. The authors suggested that music features might be coded in terms of relative position, as opposed to absolute position. However, Kostic and Cleary did not report the distance of the transposed notes. The authors stated "To rearrange the order of the notes, each note was moved to a different note's location on the staff. This process of scrambling note order was analogous to forming an anagram from a word (e.g., house to suohe)" pp 153. According to the Overlap Model (Gomez et al., 2008), letter position information is best characterized as a series of distributions. Letter transpositions might have an effect when they occur with adjacent letters. In contrast, transpositions between far away positions might produce little to no priming.

The same might be true for the feature matching process that produces familiarity detection. It is possible that nearby note transpositions might still produce a familiarity signal. In contrast, transpositions between far away features might produce a negligible familiarity signal. If the majority of note transpositions by Kostic and Cleary (2009) were not nearby transpositions, then this could have diminished the familiarity detection. Kostic and Cleary did not report the average distance of the transpositions but judging from that example they were not adjacent transpositions.

It should be noted that if the Transposition Fragments show a recognition without identification effect, it should, at least in theory, be a smaller effect compared to the Slot Specific Fragments. This is because even though letters out of position will cause lexical activation, they will still cause less activation compared to if they were in the correct position (Perea & Lupker, 2003a; 2003b; Gomez et al., 2008). This is again because letter positions are thought to be coded as distributions and in terms of general location. Shifting the letters out of position will thus cause less activation. The same should be expected for the familiarity ratings. Letters could theoretically contribute to the familiarity signal, even if they are out of position, but they should contribute to a smaller degree compared to being in the correct position.

CHAPTER 5 – EXPERIMENT 1

Method

Participants

Participants were 48 Colorado State University undergraduate students. This number was determined by the power analysis shown in the appendix. Participants received course credit for participating.

Design

Experiment 1 used a 3 (Fragment Type: Slot Specific, Relative Position, Transposition) x 2 (Study Status: Studied, Unstudied) repeated measures design.

Materials

Experiment 1 was programmed into E prime. Stimuli were 120 nine-letter words. The words were drawn from the English Lexicon Project (Balota et al., 2007). The stimuli from Experiment 1 can be found in Appendix B. There were four study and test blocks. In each study block, there were 15 study words. In each test block there were 30 word fragments. Of those 30 fragments, 15 corresponded to studied words and 15 did not correspond to studied words. Since the main manipulation occurred at test, fragments could be from each of the three conditions regardless of whether a corresponding word was studied or not. Therefore, in each block there were five Slot Specific Fragments whose corresponding word was studied and five Slot Specific Fragments whose corresponding word was not studied. There were also five

Relative Position Fragments whose corresponding word was studied and five Relative Position Fragments whose corresponding word was not studied. Finally, there were five Transposition Fragments whose corresponding word was studied and five Transposition Fragments whose corresponding word was not studied. Since there are six conditions for each word, six versions of the experiment were created so that each word appears equally often in each condition.

The test fragment always contained the second, third, seventh, and eight letters of the target nine letter word but in various positions. The Slot Specific Fragments had these letters displayed in their proper locations. For example, if the target word was DISEMBODY, the Slot Specific Fragment was _IS_ _ _OD_. The Relative Position Fragments contained those same letters but shifted one slot towards the middle of the fragment. For example, the fragment of DISEMBODY was _ _IS_OD_ _. Finally, the Transposition Fragments were made by transposing the two letters of each bigram from the Slot Specific Fragments. For example, the fragment for DISEMBODY was _SI_ _ _DO_.

One constraint that was applied was that the words did not have two of the same letters appearing in a row in the test fragments. For example, the fragment for the word WOODSHEDS (_OO_ _ _ED_) was not eligible. This is because this fragment would look identical for the first two letters in the Slot Specific (e.g., _OO_ _ _ED_) and Transposition Fragments (e.g., _OO_ _ _DE_). Another constraint that was applied is that either of the two letter sequences of the fragments could not make up a two-letter grapheme. For example, the word COALMINES was not allowed. This is because the Transposition Fragment (_AO_ _ _EN_) would greatly change the phonology of the letters since AO sounds nothing like the OA in COALMINES.

Procedure

Participants were seated at computers in separate rooms. All of the instructions and materials were displayed in a size 18 font in the center of the screen. Both the study words and test fragments appeared in all capital letters. The experiment consisted of four study and test blocks. The word font was black on a white background. The program first displayed:

> Welcome to the experiment, you will first be shown a series of words to study, the words will flash by one at a time in the center of the screen. You will later do a memory test which will be explained to you when you get to it. Press ENTER to continue.

A series of study words were then presented for two seconds each, one at a time, in the center of the screen. There were fifteen words presented in each of the four study blocks. The order of the study words was randomized for each participant. After the first study block was complete, the first test block began. The computer displayed:

> Next is the first test block. You will see word fragments. First you should rate the fragment from 0 to 10 as to how familiar it feels with respect to the words you studied in this experiment. 10 means the fragment feels highly familiar, and 0 means it does not feel familiar at all. Type your rating from 0 to 10 and press enter.

Participants then saw thirty test fragments, one at a time, in the center of the screen. The test fragments were also presented in a random order for each participant. Just below the fragment the words “Type your familiarity rating with respect to the studied words and press enter” were displayed. When a fragment appeared, participants first gave their familiarity ratings from 0 to 10. The program did not allow participants to advance if they typed anything other than a 0 to 10 response. If they did type anything other than a 0 to 10 response the same fragment and prompt reappeared. After giving a familiarity rating, participants still saw the fragment. Below the fragment the words "Type in the word that completes the fragment if you can, and press ENTER" appeared. Participants typed the word that completed the fragment if they could, and then pressed ENTER to advance to the next trial. This repeated for each of the 30 test fragments in each of the test blocks. After each test block, the next study block began. Each study block contained 15 study words, and each test block contained 30 test fragments. The 30 test fragments were made up of five of each fragment type described under materials. There were four study test blocks. Before each study block after the first, the words "next there is another study block" appeared. Before each test block after the first test block, the words "next there is another test block" appeared. At the end of the experiment, participants were asked if they spoke any languages other than English, and if so, how fluently.

Note that many of both the Relative Position and Transposition Fragments did not correspond to real words as in the above examples. However, from the perspective of the participant these should have seemed to be fragments of real words they simply could not identify. Thus, these fragments should not compromise the familiarity ratings.

Results

Identification Coding

As in prior work (e.g., Cleary & Greene, 2000), the focus was on the familiarity ratings given to unidentified word fragments. This was the case for all fragment types. Some of the Slot Specific Fragments were fragments of multiple possible alternative target words. For example, the Slot Specific Fragment _IT_ _ _BU_ is a fragment for both LITTERBUG and JITTERBUG. Using the targets that would fit the Slot Specific Fragment condition as the anchor for all three fragment conditions, if participants typed any of the possible target words that would fit into the Slot Specific version of the fragment, the trial would count as identified and not be included in the familiarity ratings under examination (as the focus here is strictly on unidentified word fragments). This criterion was kept consistent across the two conditions in which the fragment was designed to not exactly fit its target (the Relative Position and Transposition conditions); specifically, even in these two conditions, if the participant typed any of the target words that would have fit the Slot Specific Fragment, even in the Relative Position and the Transposition conditions, that trial was classified as identified. This kept the identification criterion consistent across all three fragment conditions. If participants typed any word derivative of a target word, such as typing HYDRATION in place of the target HYDRATING, it was coded as identified. This was done because the goal was to isolate familiarity detection as well as the letter features behind it, and potentially involving fully identified words, even if they were not an exact match to the target, would possibly contaminate the results with extraneous factors such as recall, the meaning behind the words, etc., as opposed to just familiarity and just the letters contributing to it. Finally, when participants typed a word other than a possible target or its derivative, typed a nonword letter string, or left the prompt blank, the trial was classified as unidentified.

Participant Analyses

Identification Rates

Though not the primary focus of the current experiments, it is important to consider how often participants were able to identify words from the fragments according to the criteria listed above. Thus, I analyzed the identification rates using a 3 (Fragment Type: Slot Specific, Relative Position, Transposition) x 2 (Study Status: Studied, Unstudied) repeated measures ANOVA which were broken down by participants. The means for this analysis are displayed in Figure 2. There was a significant effect of Fragment Type, $F_{participants}(2, 94) = 54.30$, $MSE = .01$, $p < .001$, $\eta_p^2 = .54$. Collapsing across Studied and Unstudied, Slot Specific Fragments produced higher identification rates compared to Relative Position Fragments, $t_{participants}(95) = 8.29$, $SE = .01$, $p < .001$, Cohen's $d = 1.21$, Furthermore, Slot Specific Fragments produced higher identification rates compared to Transposition Fragments, $t_{participants}(95) = 9.62$, $SE = .01$, $p < .001$, Cohen's $d = 1.41$. There was not a significant difference between Relative Position and Transposition Fragments, $t_{participants}(95) = 1.33$, $SE = .01$, $p = .19$, Cohen's $d = 0.19$. There was also a significant effect of Study Status on identification rates, $F_{participants}(1, 47) = 98.95$, $MSE = .01$, $p < .001$, $\eta_p^2 = .68$, with higher identification rates occurring for fragments whose target word had been studied.

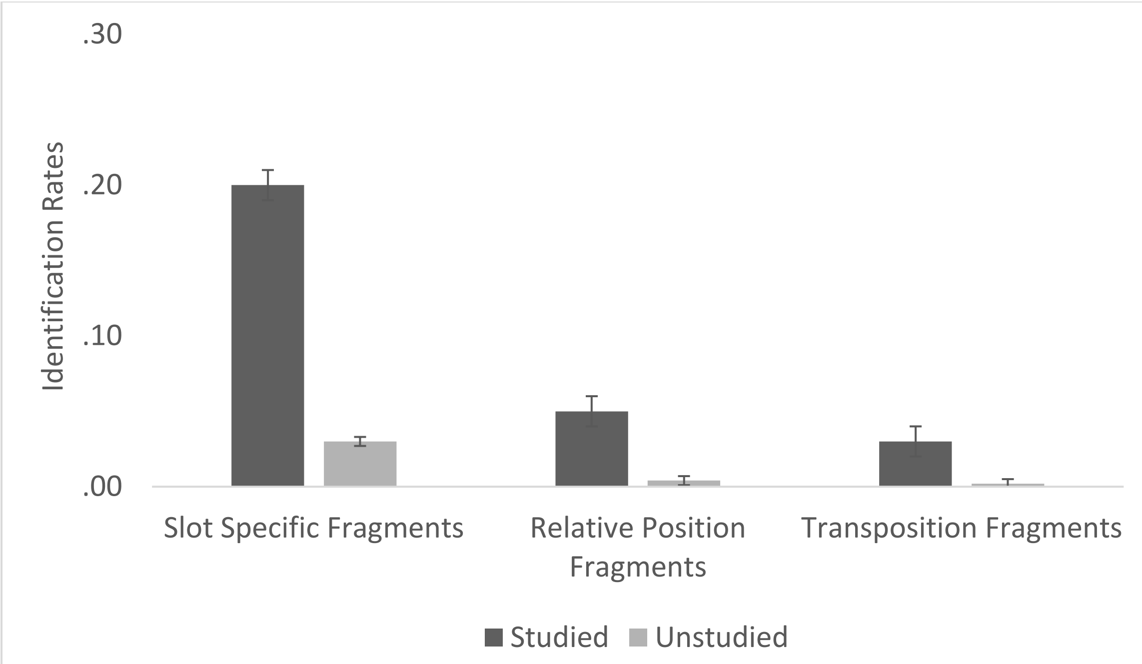

Figure 2. Mean identification rates by participants in Experiment 1. The bars represent standard errors.

The main effect of Study Status on identification rates was qualified by a significant Fragment Type x Study Status interaction, $F_{participants}(2, 94) = 38.04$, $MSE = .004$, $p < .001$, $\eta_p^2 = .45$. Thus, I examined the effect of Study Status for each Fragment Type separately. Studying the target word produced higher identification rates for Slot Specific Fragments, $t_{participants}(47) = 12.96$, $SE = .01$, $p < .001$, Cohen's $d = 2.48$. Studying the target word also resulted in higher identification rates for Relative Position Fragments, $t_{participants}(47) = 3.75$, $SE = .01$, $p = .003$, Cohen's $d = 0.72$. Finally, there was not a significant effect of Study Status on Transposition Fragments, $t_{participants}(47) = 2.03$, $SE = .01$, $p = .33$, Cohen's $d = 0.39$. Thus, the effect of Study Status was largest for Slot Specific Fragments, smaller for Relative Position Fragments, and non-significant for Transposition Fragments. However, this analysis should be interpreted with a great degree of caution for reasons I will explain in the General Discussion.

Familiarity Ratings for Unidentified Fragments

The primary data of interest were the familiarity ratings given to fragments that went unidentified. These were examined to determine whether a recognition without identification effect is present in each condition, and whether the type of fragment impacted the magnitude of the recognition without identification effect, as this is the present metric of word familiarity. For this, I conducted a 3 (Fragment Type: Slot Specific, Relative Position, Transposition) x 2 (Study Status: Studied, Unstudied) repeated measures ANOVA on familiarity ratings during identification failure broken down by participants. The means for this analysis are displayed in Figure 3. There was a significant effect of Fragment Type, $F_{participants}(2, 94) = 6.93$, $MSE = 0.13$, $p = .002$, $\eta_p^2 = .13$. There was not a significant difference in familiarity ratings for unidentified fragments between the Slot Specific and Relative Position fragments, $t_{participants}(95) = -1.67$, $SE = 0.04$, $p = .099$, Cohen's $d = -0.17$. There was also not a significant difference between Slot Specific and Transposition Fragments, $t_{participants}(95) = 1.96$, $SE = 0.05$, $p = .053$, Cohen's $d = 0.20$. Participants did give higher familiarity ratings to Relative Position Fragments compared to Transposition Fragments, $t_{participants}(95) = 3.65$, $SE = 0.44$, $p < .001$, Cohen's $d = 0.37$.

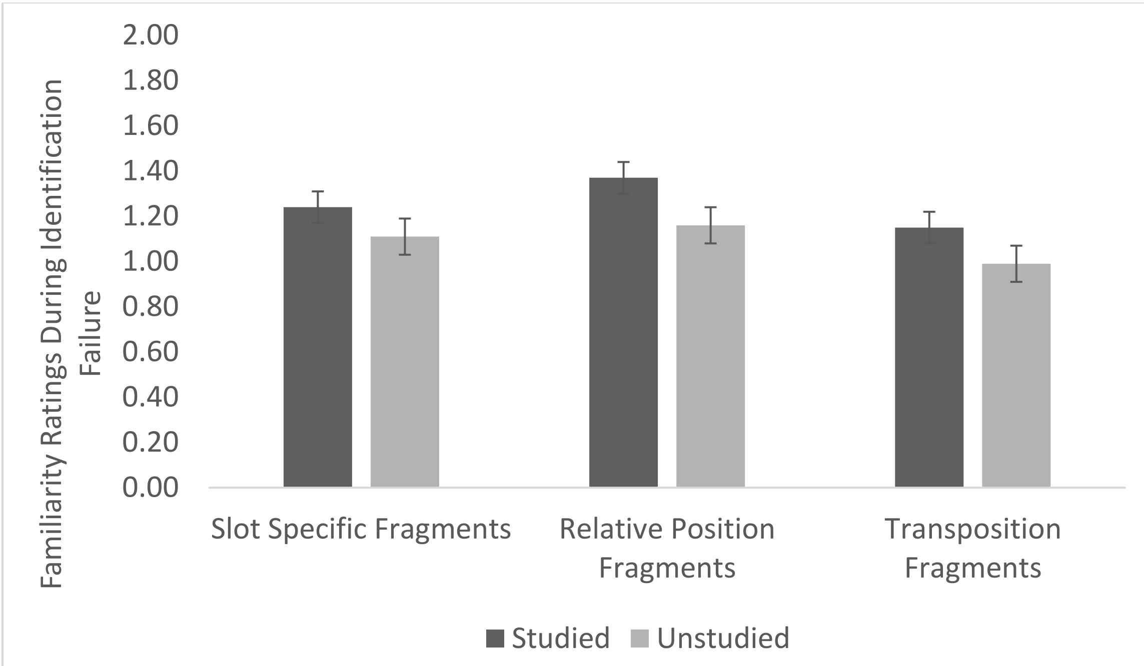

Figure 3. Mean familiarity ratings for unidentified fragments by participants in Experiment 1. The bars represent standard errors. Note that the recognition without identification effect was roughly equivalent across fragment types.

Most importantly, there was a significant main effect of Study Status, $F_{participants}(1, 47) = 8.26$, $MSE = 0.24$, $p = .006$, $\eta_p^2 = .15$, with fragments corresponding to a studied word receiving higher familiarity ratings. The difference in ratings between the Studied and Unstudied conditions is the recognition without identification effect. Note that the magnitude of the recognition without identification effect was unaffected by the type of fragment. There was no significant Fragment type x Study Status interaction on familiarity ratings during identification failure, $F < 1$.

Although prior work (e.g., Cleary, 2002; Cleary & Greene, 2000) separately examined recognition ratings during identification success (separately from during identification failure), recognition ratings during identification success (or recognition WITH identification) cannot be analyzed in the current experiments because identification rates were too low. Nearly every participant lacked one or more conditions needed to run the needed analysis.

Item Analyses

Identification Rates

Next, I analyzed the item means. For these analyses fragments were grouped by the target word in question. From there, each trial was put into the same six conditions as the participant analyses, except that now each target word and the accompanying trials was treated as a participant.

I first examined the identification rates grouped by items using a 3 (Fragment Type: Slot Specific, Relative Position, Transposition) x 2 (Study Status: Studied, Unstudied). The means for this analysis are displayed in Figure 4. There was a significant main effect of Fragment Type, $F_{items}(2, 238) = 72.00$, $MSE = .01$, $p < .001$, $\eta_p^2 = .38$. Collapsing across Study Status, Slot Specific Fragments produced higher identification rates than Relative Position Fragments, $t_{items}(239) = 10.53$, $SE = .01$, $p < .001$, Cohen's $d = 0.91$. Slot Specific Fragments also produced higher identification rates than Transposition Fragments, $t_{items}(239) = 10.25$, $SE = .01$, $p < .001$, Cohen's $d = 0.89$. There was not a significant difference in identification rates between Relative Position and Transposition Fragments, $t < 1$. Additionally, there was a significant main effect of Study Status, where studying the target word led to higher identification rates overall, $F_{items}(1, 119) = 128.11$, $MSE = .01$, $p < .001$, $\eta_p^2 = .52$.

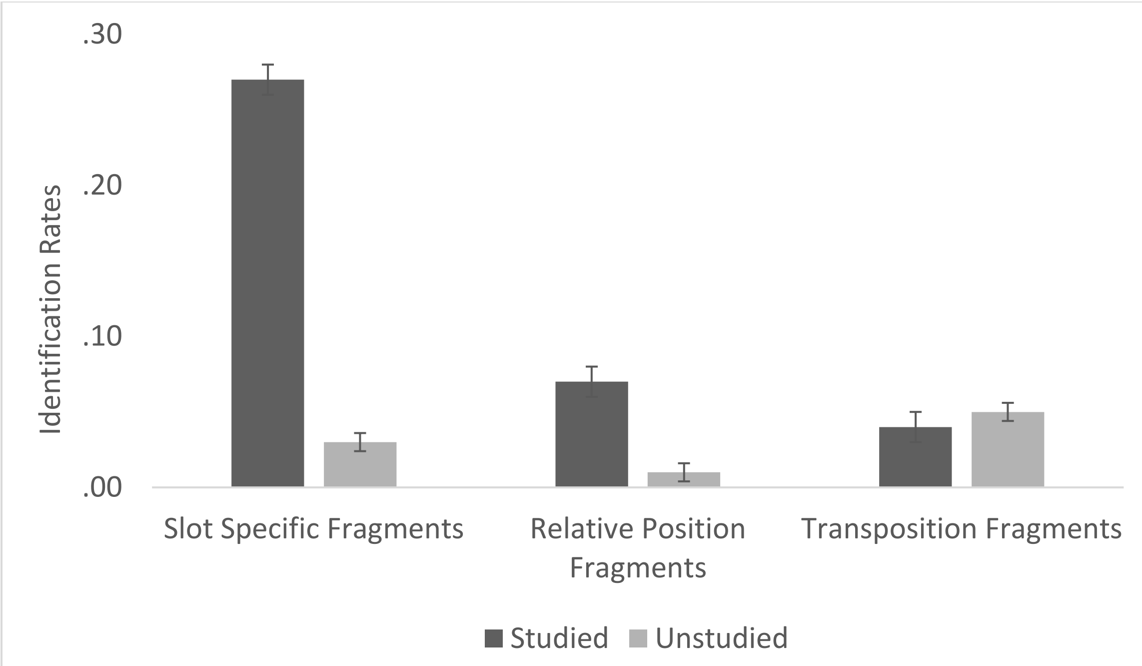

Figure 4. Mean identification rates by items in Experiment 1. The bars represent standard errors.

The main effect of Study Status on identification rates was qualified by a significant Study Status x Fragment Type interaction, $F_{items}(2, 238) = 66.73$, $MSE = .01$, $p < .001$, $\eta_p^2 = .36$. Given the significant interaction, I examined the effect of Study Status separately for each Fragment Type. For the Slot Specific Fragments, Studying the accompanying word produced higher identification rates, $t_{items}(239) = 15.54$, $SE = .02$, $p < .001$, Cohen's $d = 1.86$. Studying the target word also produced higher identification rates for Relative Position Fragments, $t_{items}(239) = 4.44$, $SE = .02$, $p < .001$, Cohen's $d = 0.53$. In contrast, there was no significant effect of Study Status for Transposition Fragments, $t < 1$. As with the participant analysis, the identification rates should be interpreted with caution for reasons I will explain in the General Discussion.

Familiarity Ratings for Unidentified Fragments

Turning again to the primary question, I conducted a 3 (Fragment Type: Slot Specific, Relative Position, Transposition) x 2 (Study Status: Studied, Unstudied) repeated measures ANOVA on familiarity ratings for unidentified fragments, which were grouped by items this time. The means for this analysis are displayed in Figure 5. There was a significant main effect of Fragment Type, $F_{items}(2, 238) = 6.17$, $MSE = 0.37$, $p = .002$, $\eta_p^2 = .05$. Slot Specific Fragments received lower familiarity ratings than Relative Position Fragments, $t_{items}(239) = -2.24$, $SE = 0.08$, $p = .03$, Cohen's $d = -0.15$. Relative Position Fragments received higher familiarity ratings than Transposition Fragments, $t_{items}(239) = 3.61$, $SE = 0.08$, $p < .001$, Cohen's $d = 0.29$. Finally, Slot Specific Fragments did not receive higher familiarity ratings than Transposition Fragments, $t_{items}(239) = 1.11$, $SE = 0.08$, $p = .27$, Cohen's $d = 0.07$.

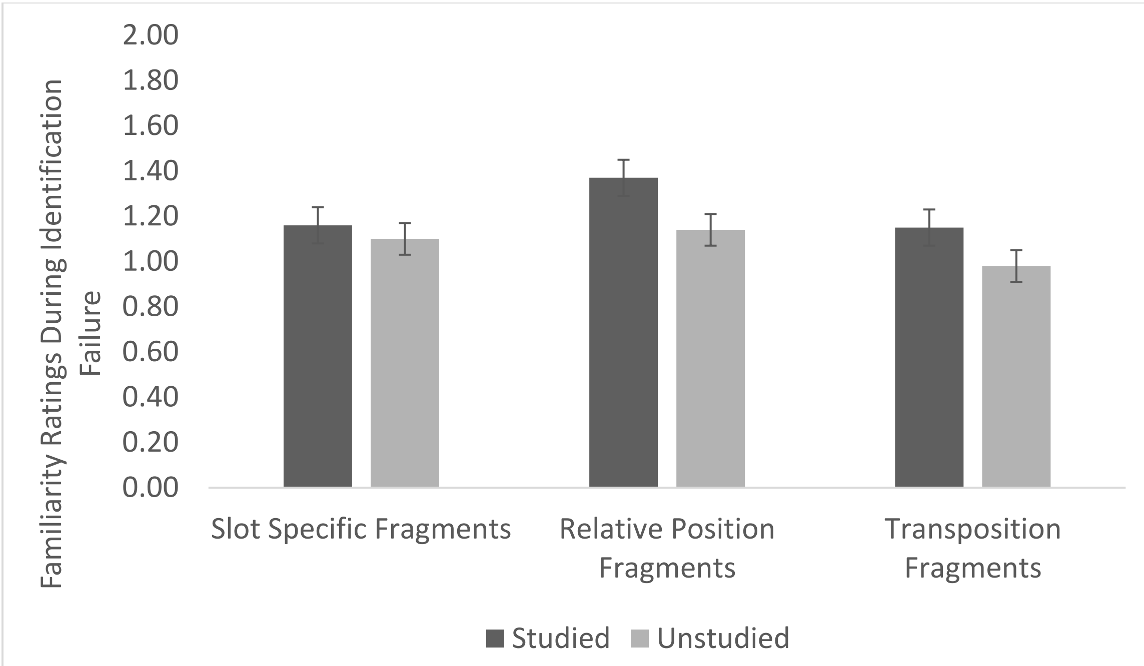

Figure 5. Mean familiarity ratings for unidentified fragments by items in Experiment 1. The bars represent standard errors. Note that the recognition without identification effect was roughly equivalent across fragment types.

Most importantly, there also was a significant main effect of Study Status on familiarity ratings given to unidentified fragments, $F_{items}(1, 119) = 6.24$, $MSE = 0.68$, $p = .01$, $\eta_p^2 = .05$. Fragments corresponding to studied words received higher familiarity ratings than fragments that did not correspond to studied words. There was not a significant Fragment Type x Study Status interaction, $F_{items}(2, 238) = 1.19$, $MSE = 0.36$, $p = .31$, $\eta_p^2 = .01$. This mirrors the pattern found with the participant analysis. As noted earlier, the recognition ratings given during identification success could not be examined because almost every participant lacked one of the six necessary conditions.

Summary

These results are consistent with a flexible processing approach to word familiarity. Letters do not seem to need to be in the same absolute or relative positions between study and test. Instead, letters that are out of absolute or even relative place appear to be able to contribute equally to the familiarity signal theorized to underlie the recognition without identification effect to produce a recognition without identification effect of comparable magnitude.

CHAPTER 6 – EXPERIMENT 2

One problem with Experiment 1 could have been the potential effect of shifting letter positions. In Experiment 1, a word like BANDWAGON appeared as _AN_ _ _GO_, _ _AN_GO_ _, or _NA_ _ _OG_. It is possible that shifting the slots to be closer to the middle of the word could have had an effect, possibly related to Relative Position Fragments showing higher familiarity ratings overall. Typically, only the first and last letter positions are especially significant (e.g., Jordan et al., 2003; Johnson & Eisler, 2012; Huebert et al., 2022), though the possible significance of being closer to the interior has not been investigated with regard to word familiarity. Thus, Experiment 2 addressed this by shifting slots in a different direction. In Experiment 1, the letters in the Slot Specific Fragments were in the second, third, seventh, and eighth positions in nine letter words. Those letters shifted one slot to the center for the Relative Position Fragments. In Experiment 2, for the Slot Specific Fragments, the letters appeared in the third, fourth, sixth, and seventh positions. The Relative Position Fragments then shifted the letters outwards. For example, if the study word was BANDWAGON, the test fragments were _ _ND_AG_ _ in the Slot Specific condition, _ ND_ _ _AG_ in the Relative Position condition, or _ _DN_GA_ _ in the Transposition condition. If the pattern from Experiment 1 is replicated, then it is unlikely that it had anything to do with the inward shift in the Relative Position condition.

Method

Participants

Participants were 48 undergraduate and graduate students from Colorado State University. This number was based on the same power analysis as Experiment 1 and it is shown in the Appendix. The undergraduates were either given course credit or ten dollars for participating, while the graduate students were paid ten dollars.

Design

The design was the same as in Experiment 1.

Materials

The fragments in Experiment 2 contained the third, fourth, sixth, and seventh letters from the target word. The stimuli from Experiment 2 can be found in Appendix B. The Slot Specific Fragment contained those letters in their proper positions. For example, the Slot Specific Fragment for EXHUSBAND would be _ _HU_BA_ _. The Relative Position Fragments would contain those same letters but shifted one slot outwards each. For example, the Relative Position Fragment for EXHUSBAND would be _HU_ _ _BA_. Finally, the Transposition Fragments would have the letters of each of the two bigrams in the Slot Specific condition transposed. For example, the Transposition Fragment for EXHUSBAND would be _ _UH_AB_ _.

The 120 words were mostly the same as those used in Experiment 1. The only difference was that some words were replaced if they had two identical letters in a row in the third and fourth or sixth and seventh positions. For example, in Experiment 1, JITTERBUG would be _IT_ _

_BU_, as a Slot specific fragment, or _TI_ _ _UB_ as a Transposition Fragment, which was fine. In Experiment 2, this would have been _ _TT_RB_ _ as a Slot Specific Fragment, and _ _TT_BR_ as a Transposition Fragment. Thus, it was replaced by a different word in Experiment 2.

The constraint regarding two letter graphemes in Experiment 1 was also applied to the words in Experiment 2 but at different letter positions. For example, the word SNOWFLAKE would not be eligible. This is because the Slot Specific Fragment would be _ _OW_FL_ _ and the Transposition Fragment would be _ _WO_LF_ _ which has very different phonology.

Procedure

Experiment 2 used the same procedure as Experiment 1. The only difference was the letter positions used in the word fragments discussed above.

Results

Participant Analyses

Identification Rates

The results were coded and analyzed in the same way as Experiment 1. Starting with identification rates grouped by participants, I conducted a 3 (Fragment Type: Slot Specific, Relative Position, Transposition) x 2 (Study Status: Studied, Unstudied) repeated measures ANOVA on identification rates. The means for this analysis are displayed in Figure 6. There was a significant main effect of Fragment Type on identification rates, $F_{participants}(2, 94) = 38.07$, $MSE = .01$, $p < .001$, $\eta_p^2 = .45$. Slot Specific Fragments produced higher identification rates compared to Relative Position Fragments, $t_{participants}(95) = 6.13$, $SE = .01$, $p < .001$, Cohen's $d = 0.82$. Slot

Specific Fragments also produced higher identification rates compared to Transposition Fragments, $t_{participants}(95) = 8.44$, $SE = .01$, $p < .001$, Cohen's $d = 1.12$. Relative Position Fragments also produced higher identification rates compared to Transposition Fragments, $t_{participants}(95) = 2.31$, $SE = .01$, $p = .02$, Cohen's $d = 0.31$. There was also a significant main effect of Study Status, $F_{participants}(2, 47) = 77.13$, $MSE = .01$, $p < .001$, $\eta_p^2 = .62$, where studying the target word led to higher identification rates.

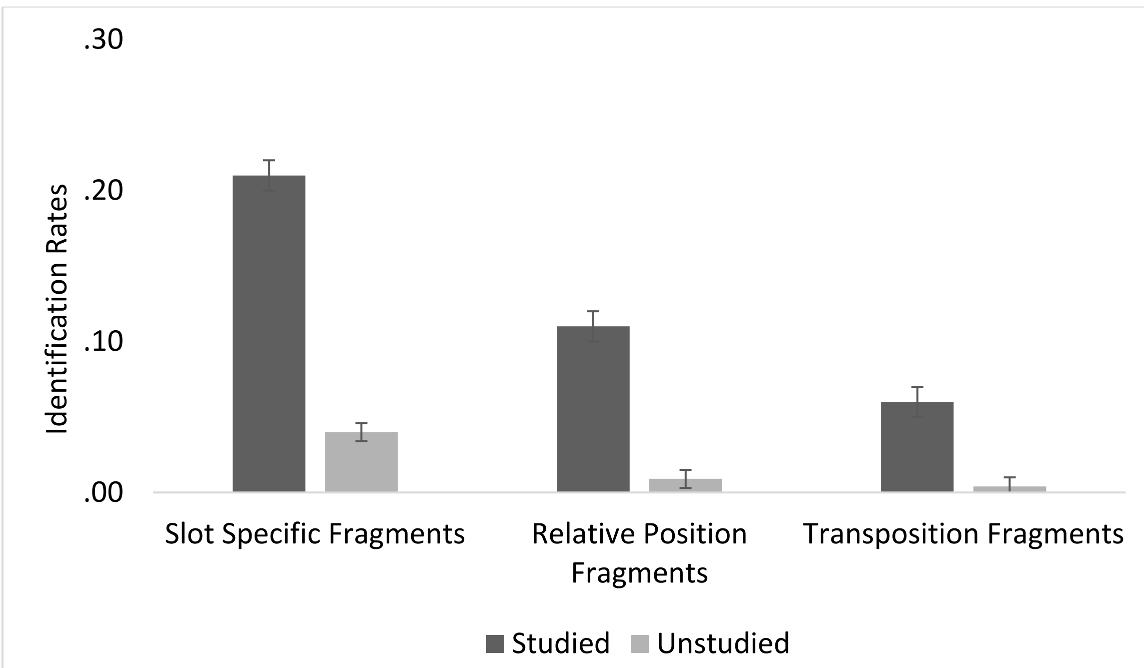

Figure 6. Mean identification rates by participants in Experiment 2. The bars represent standard errors.

The main effect of Study Status on identification rates was qualified by a significant Fragment Type x Study Status interaction, $F_{participants}(2, 94) = 25.87$, $MSE = .003$, $p < .001$, $\eta_p^2 = .36$. Thus, I examined the effect of Study Status separately for each Fragment Type. For Slot Specific Fragments, studying the target word led to higher identification rates, $t_{participants}(47) =$

11.06, *SE* = .02, $p < .001$, Cohen's $d = 2.07$. For Relative Position Fragments, studying the target word also led to higher identification rates, $t_{participants}(47) = 6.37$, *SE* = .02, $p < .001$, Cohen's d = 1.19. Finally, for Transposition Fragments, studying the target word produced higher identification rates, $t_{participants}(47) = 3.76$, *SE* = .02, $p = .002$, Cohen's $d = 0.70$. Thus, though studying the target word had an effect for all three fragment types, the effect of studying the target word was largest for Slot Specific Fragments, followed by Relative Position Fragments, followed by Transposition Fragments.

Familiarity Ratings for Unidentified Fragments

Once again, the primary data of interest were the familiarity ratings given to fragments that went unidentified. These were examined to determine whether a recognition without identification effect is present in each condition, and whether the type of fragment impacted the magnitude of the recognition without identification effect, as this is a metric of word familiarity. Thus, I analyzed familiarity ratings given to unidentified fragments grouped by participants. These were analyzed using a 3 (Fragment Type: Slot Specific, Relative Position, Transposition) x 2 (Study Status: Studied, Unstudied), repeated measures ANOVA. The means are displayed in Figure 7. Unlike Experiment 1, there was not a significant main effect of Fragment Type, $F_{participants}(2, 94) = 3.00$, *MSE* = 0.19, $p = .06$, $\eta_p^2 = .05$. However, consistent with Experiment 1, there was a significant main effect of Study Status, $F_{participants}(1, 47) = 9.67$, *MSE* = 0.22, $p = .003$, $\eta_p^2 = .17$, where participants gave higher familiarity ratings to unidentified fragments corresponding to studied word compared to unidentified fragments not corresponding to studied words. Also consistent with Experiment 1, there was not a significant Fragment Type x Study Status interaction, $F_{participants}(2, 94) = 1.09$, *MSE* = 0.19, $p = .34$, $\eta_p^2 = .02$.

As in Experiment 1, the recognition ratings given during identification success could not be examined because almost every participant lacked one of the six necessary conditions.

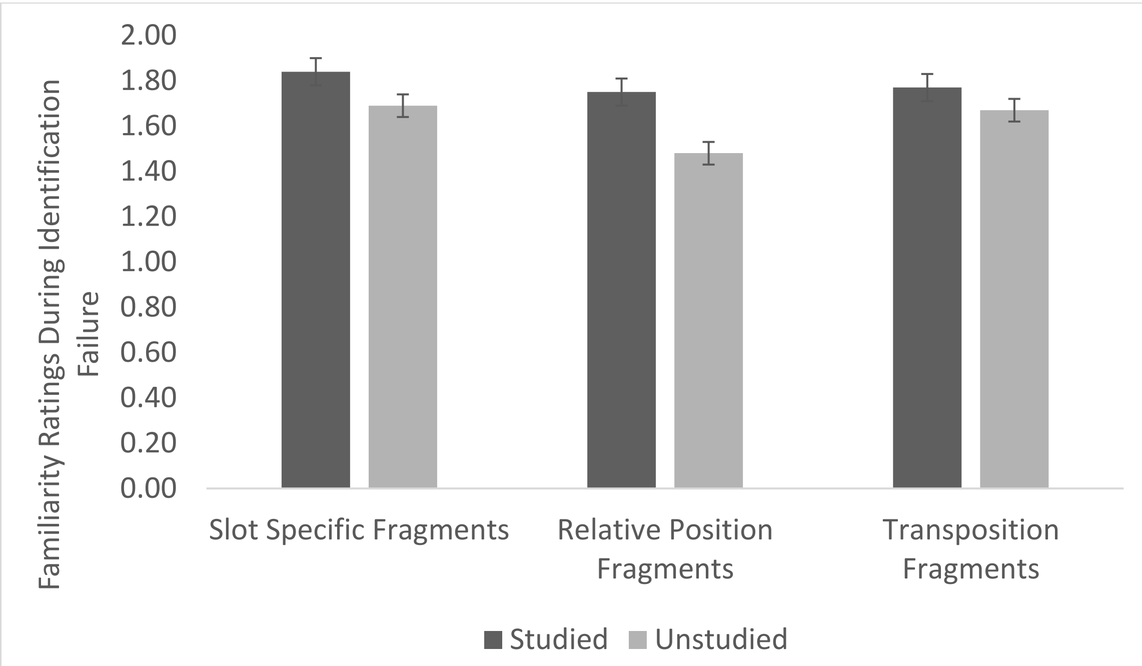

Figure 7. Mean familiarity ratings for unidentified fragments by participants in Experiment 2. The bars represent standard errors. Note that the recognition without identification effect was roughly equivalent across fragment types.

Item Analyses

Identification Rates

Grouping by items, next I examined identification rates. I conducted a 3 (Fragment Type: Slot Specific, Relative Position, Transposition) x 2 (Study Status: Studied, Unstudied) repeated measures ANOVA on identification rates. The means for this analysis are displayed in Figure 8. There was a significant main effect of Fragment Type, $F_{items}(2, 238) = 46.28$, $MSE = .56$, $p < .001$, $\eta_p^2 = .28$. Slot Specific Fragments produced higher identification rates than Relative Position Fragments, $t_{items}(119) = 6.76$, $SE = .01$, $p < .001$, Cohen's $d = 0.59$. Slot Specific Fragments also produced higher identification rates than Transposition Fragments, $t_{items}(119) = 9.31$, $SE = .01$, $p < .001$, Cohen's $d = 0.81$. Finally, Relative Position Fragments produced higher identification rates compared to Transposition Fragments, $t_{items}(119) = 2.55$, $SE = .01$, $p = .01$, Cohen's $d = 0.22$. As in the participants analysis, there was also a significant main effect of Study Status, where studying the target word led to higher identification rates, $F_{items}(1, 119) = 139.11$, $MSE = .02$, $p < .001$, $\eta_p^2 = .54$.

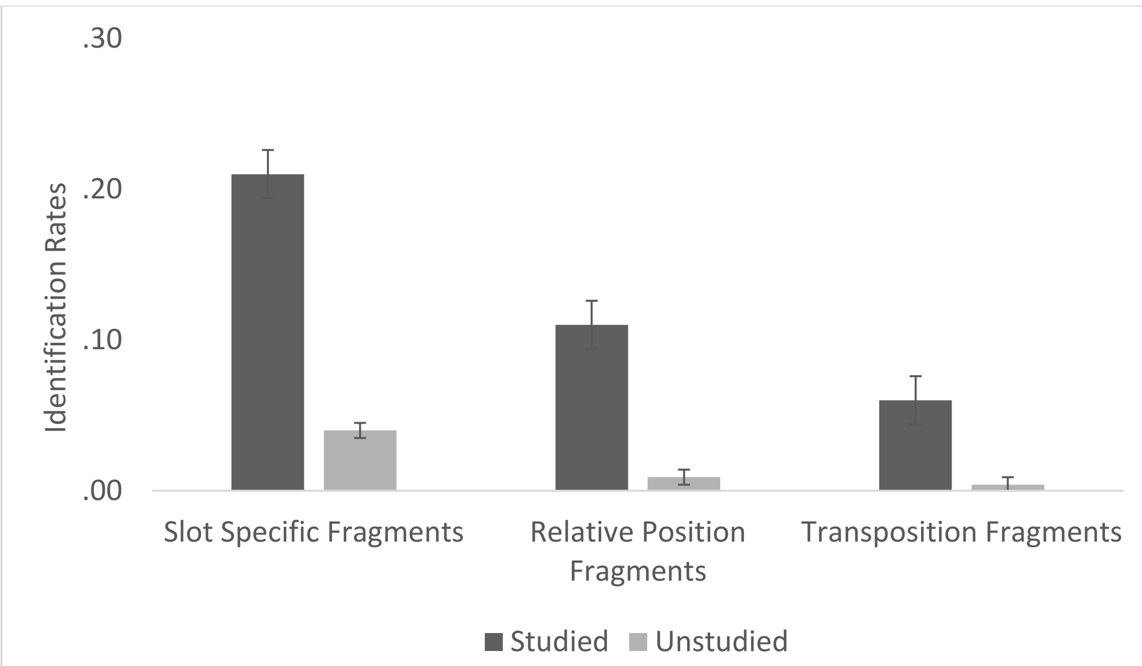

Figure 8. Mean identification rates by items in Experiment 2. The bars represent standard errors.

Both of these main effects were qualified by a significant Study Status x Fragment Type interaction, $F_{items}(2, 238) = 22.04$, $MSE = .001$, $p < .001$, $\eta_p^2 = .16$. Thus, I examined the effect of Study Status for each Fragment Type separately. For Slot Specific Fragments, studying the target word produced higher identification rates, $t_{items}(119) = 12.58$, $SE = .01$, $p < .001$, Cohen's $d = 1.50$. For the Relative Position fragments, studying the target word produced higher identification rates, $t_{items}(119) = 7.24$, $SE = .01$, $p < .001$, Cohen's $d = 0.86$. Finally, for Transposition Fragments, studying the target word produced higher identification rates, $t_{items}(119) = 4.27$, $SE = .01$, $p < .001$, Cohen's $d = 0.51$. Thus, although studying the target word produced higher identification rates for all three Fragment Types, this effect was largest for Slot Specific Fragments, followed by Relative Position Fragments, followed by Transposition Fragments.

Familiarity Ratings for Unidentified Fragments

Next, I examined the findings of primary interest, the familiarity ratings for unidentified fragments, grouped by items. The means for this analysis are displayed in Figure 9. I conducted a 3 (Fragment Type: Slot Specific, Relative Position, Transposition) x 2 (Study Status: Studied, Unstudied) repeated measures ANOVA on familiarity ratings given to unidentified fragments. There was not a significant main effect of Fragment Type, $F_{items}(2, 238) = 2.12$, $MSE = 0.77$, $p = .12$, $\eta_p^2 = .02$. Similar to the participant means, there was a significant main effect of Study Status. Participants gave higher familiarity ratings to unidentified fragments corresponding to a study word compared to unidentified fragments that did not correspond to a studied word, $F_{items}(1, 119) = 4.31$, $MSE = 0.62$, $p = .04$, $\eta_p^2 = .04$. Finally, there was not a significant Study Status x Fragment Type interaction, $F < 1$. This mirrors what was found in the participant analysis. Once again, the familiarity ratings given when identification was successful could not be analyzed because nearly every participant lacked responses in one or more of the required conditions.

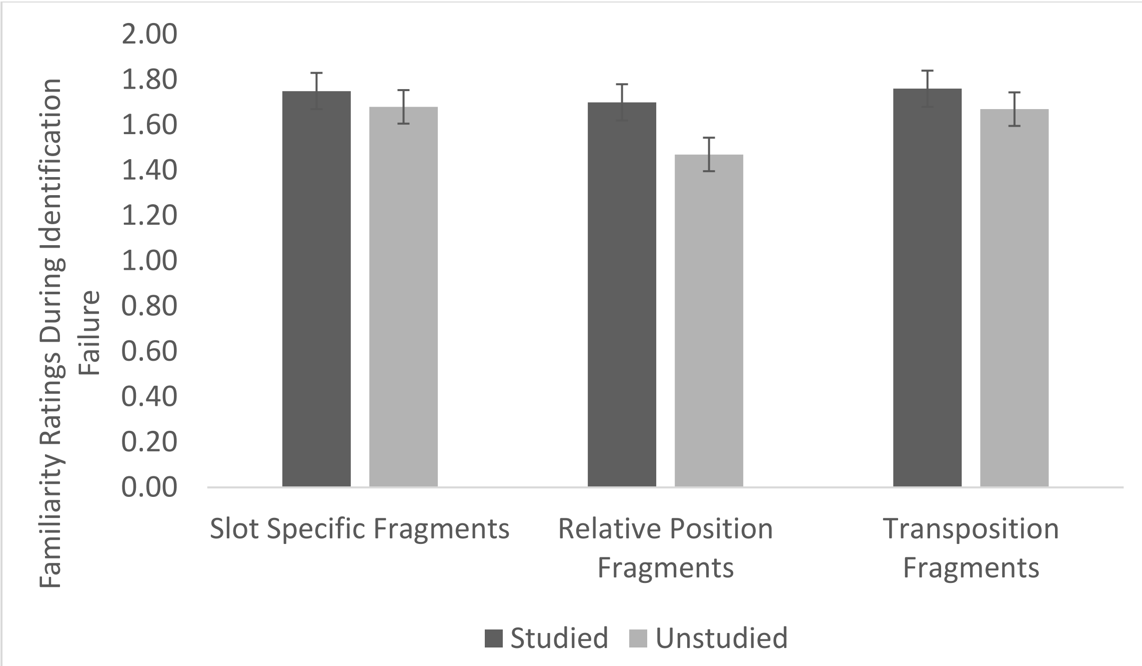

Figure 9. Mean familiarity ratings for unidentified word fragments by items in Experiment 2. The bars represent standard errors. Note that the recognition without identification effect was roughly equivalent across fragment types.

Summary

Similar to Experiment 1, these results support a flexible approach to letter position matching. Letters that do not maintain their absolute or relative positions seem to still be able to contribute to word fragment familiarity, as shown by the fact that the recognition without identification effect was impervious to the differences among the types of fragments investigated here; roughly equivalent differences in familiarity ratings were shown for all three fragment types during identification failure. An implication of these findings is that the letter matching mechanism presumed to underlie familiarity signal computation does not rely on an absolute or even a relative positional coding, but rather, uses surrounding letter positions in its feature-matching mechanism.

CHAPTER 7 – GENERAL DISCUSSION

Summary of the Current Results

To briefly summarize the main findings regarding the familiarity ratings for unidentified word fragments, both Experiment 1 and Experiment 2 showed similar results. Both Experiments showed a significant effect of studying the target word corresponding to the test word fragment. Studying the targets led to higher familiarity ratings for unidentified fragments than when the targets for the fragment were not studied. This recognition without identification effect did not change based on whether the letters appeared in the same exact (absolute) positions, the same relative positions, or were transposed. This was found for both participant and item analyses. This result suggests that letters in the test fragment do not need to be in their original positions, or even in their original relative positions, for the feature-matching-based familiarity signal computation presumed to underlie the recognition without identification effect to take place. Instead, this feature-matching process appears to be quite flexible and robust to alterations in letter position between the memory trace and the test fragment.

Though the primary focus of this dissertation is on the word fragment recognition without identification effect (which concerns the difference in familiarity ratings for unidentified fragments of studied vs. unstudied words), Experiments 1 and 2 also uncovered additional patterns that were more peripheral to the present goals as well. The first concerns the main effect of Fragment Type on familiarity ratings given to unidentified word fragments. The second concerns identification rates.

Starting with the main effect of Fragment Type on familiarity ratings given to unidentified word fragments, Experiment 1 showed a significant overall difference in familiarity ratings for unidentified fragments depending on Fragment Type when collapsing across Study Status, with Relative Position Fragments showing the highest overall familiarity ratings (irrespective of study-status). This was found for both the participant and item analyses. However, no significant main effect of Fragment Type was found in Experiment 2.

Turning to the identification rates, Experiment 1 demonstrated that studying the target led to higher identification rates. However, this effect also changed depending on the Fragment Type. Experiment 1 showed that Study Status had a significant effect for both Slot Specific and Relative Position Fragments. This effect was smaller though for Relative Position Fragments. This effect was also not found for Transposition Fragments. This same pattern was found for both participant and item analyses. Experiment 2 also showed a significant effect of Study Status on identification rates, but this effect changed depending on the Fragment Type. Studying the target led to the largest increase in identification rates for Slot Specific Fragments, a smaller increase for Relative Position Fragments, and an even smaller increase for Transposition Fragments. This was consistent across item and subject analyses. Finally, there was also a significant effect of Fragment Type on identification rates in both Experiments. Collapsing across Study Status, Slot Specific Fragments produced the highest identification rates, followed by Relative Position Fragments, followed by Transposition Fragments. This was again consistent across participant and item analyses.

Letter Position, Word Familiarity and Word Reading: Theoretical Implications

Regarding the primary patterns of interest—those concerning the recognition without identification effect—the overall pattern of results suggests that letters do not need to be in the same slots (or absolute positions) between study and test in order to produce the familiarity-based discriminability that is theorized to underlie the word fragment recognition without identification effect. Slot-specific encoding was the traditional assumption made in the literature on word processing (McClelland & Rumelhart, 1981; Rumelhart & McClelland, 1982; Coltheart et al., 1993; Coltheart et al., 2001; Zorzi et al., 1998), and implicit in research on the feature-matching mechanism theorized to drive word fragment recognition without identification is this same assumption (Cleary, 2002; Cleary & Greene, 2000, 2001). The present results not only suggest that absolute letter position is not a necessary requirement for the word fragment recognition without identification effect, but they further suggest that letters do not even need to maintain relative positioning; relative-position encoding is an alternative theory in the word processing literature (Peressotti & Grainger, 1999; Grainger et al., 2006). Altering relative positioning (using Transposed Fragments) did not even significantly reduce the magnitude of the word fragment recognition without identification effect.

The present findings suggest that the letter matching process behind the familiarity signal computation theorized to underlie the word fragment recognition without identification effect might operate in more of a flexible and overlapping manner. Letters that are out of place in the test fragment can still be matched to a word representation in a memory trace to contribute to the familiarity signal theorized to drive the familiarity-based discriminability, and to the same degree as when they are in their originally encoded positions. This was illustrated by the finding that even when letters did not maintain both the same slot specific positions or the same relative positions, participants were still able to distinguish between fragments that corresponded to studied words and fragments that did not, and to the same degree in each case. For example, compared to if the target word had not been studied, studying a word such as EXHUSBAND led to a greater sense of familiarity and to the same degree with an unidentified fragment corresponding to it, regardless of whether that fragment was a Transposition Fragment _ _UH_AB_ _, a Relative Position Fragment _HU_ _ _BA_, or a Slot Specific Fragment _XH_ _ _AN_.

The mechanism uncovered or implied here seems to be similar in some respects to that which has emerged from the research demonstrating word activation with transposed letters (Chambers, 1979; Andrews, 1996; Perea & Lupker, 2003a, 2003b; Rayner et al., 2007; Gomez et al., 2008). As discussed earlier, letters that are out of position do still seem to cause activation of words (as measured using other paradigms in the psycholinguistics literature). The activation is theorized to be generally less compared to when the letters are in the correct positions, based on patterns such as Perea and Lupker's (2003a) finding that if the target word was USHER, the prime UHSER, would decrease lexical decision speed more than UFNER. This is because letter location is thought to be most strongly associated with the correct location, but also located with the surrounding locations.

However, note that in the present study, the word fragment recognition without identification effect was largely impervious to even transposing letters in the test fragment. This suggests that there is something else going on in the process of matching the letters of a later encountered test fragment to the letters stored in word representations memory other than matching absolute or relative positions, and even more robustly than perhaps the Gomez et al. (2008) Overlap Model would predict. Although it could be that word representations in memory do not contain absolute letter position information, that seems unlikely, given people's ability to spell and write words. It may instead suggest that the feature-matching mechanism presumed to underlie word fragment familiarity detection itself operates robustly and flexibly to produce a familiarity signal. It could still be the case that letters are encoded into memory in a slot specific manner with precise location information when they are studied and are retained that way in the memory trace but the later encountered letters within the word fragment are matched up in a flexible manner. For example, consider again the word BANDWAGON. It may be that when any word or fragment with the letter N in the fourth position is encountered later, rather than just trying to match it up with a potential N in the fourth position, the feature matching mechanism will also try to match the letter N with letters stored in the adjacent or nearby positions as well.

As far as why a feature-matching based familiarity detection mechanism should operate so robustly and be potentially impervious to letter transpositions, if the aforementioned theory that familiarity detection serves to direct attention inward toward memory retrieval effort is correct (Cleary et al., 2023), a robust familiarity detection process could potentially facilitate the launching of word retrieval in a highly efficient manner. For example, if only enough letter features need to be extracted to launch a search based on those extracted features, that may be enough to facilitate word retrieval in many cases, including in impoverished sensory situations. By focusing on unidentified word fragments, the present study is possibly zeroing in on instances in which retrieval did not succeed or come to completion but the familiarity detection itself that often (but not always) leads to successful identification still occurred. If so, this makes the methodology used here a useful method for continuing to investigate familiarity detection itself. However, additional approaches will be needed in the future to determine familiarity's possible role in directing word retrieval itself.

The current results also add to the growing literature on the patterns between reading words and word familiarity detection as measured using the recognition without identification paradigm. As noted earlier, there are some striking similarities between findings from tasks on reading and findings from tasks on word familiarity. For example, Huebert and Cleary (2022) found evidence that the first and last letter positions carry more weight in the production of word familiarity. This parallels many findings in the word reading literature on how the first and last letter positions carry more weight in word identification compared to the interior letters (e.g., Jordan et al., 2003; Rayner et al., 2007; Johnson & Eisler, 2012). The present results suggest that just as letters activate words when those letters are out of position (e.g., Perea & Lupker, 2003a, 2003b; Gomez et al., 2008), letters also can contribute to familiarity detection when out of position.

Limitations and Future Improvements

There are certainly some improvements that could be made when taking the present approach in future investigations, specifically with regard to the identification rates. The instructions stated that participants should type the word that completes the fragment if they could. A limitation of these instructions could be that participants did not know what to do in instances where they recognized a fragment as containing letters of a studied word, but that those letters were out of position, for either Relative Position or Transposition Fragments. The intention was that participants would simply think these were fragments of different words they could not identify. This was at least some of the time not the case, as participants sometimes typed the target word, even though it would not fit either Relative Position or Transposition Fragments. It will be important in future research to examine the effects of different identification criteria and instructions on both identification rates and the patterns reported here, such as by directly comparing different instruction conditions.

Demonstrating that the fragments can still cue memory of the associated word, even with the letters out of position, was certainly a worthwhile finding. This finding demonstrates that flexible coding is not necessarily just tied to the fast short-term activation of words involved in reading. Flexible coding also plays a role in what are usually conceived of as longer-term processes. However, it is difficult to draw any direct comparisons of identification rates between the fragment types. Participants might have hesitated to type in words that did not match up perfectly with the fragments, even when they did come to mind for the Relative Position or Transposition Fragments. Thus, the findings on identification rates do suggest long-term priming from out of place letters, but direct comparisons between conditions should be made with great caution.

In future experiments, a solution could be to ask participants if the fragment reminds them of a studied word, as opposed to asking them if they can think of a word that fits the fragment. Participants could possibly be told that they should type in a studied word even if the letters do not match up with the fragment. This way, participants would not hesitate to type in a studied word that the fragment corresponds to. A risk of this procedure would be participants knowing or potentially knowing the purpose of the experiment. However, this would still not help participants distinguish studied from unstudied fragments. Furthermore, adding these experiments would be a nice contrast to the experiments already done. The experiments already done had the advantage of ideally keeping participants unaware of the central question of the experiments. However, this could have come at the cost of unclear identification rates. Replicating these two experiments with the different instructions would have the advantage of more reliable identification data, but at the cost of participants potentially figuring out the nature of the experiment.

It is worth noting that the potential issue of participants recognizing that a fragment contained out of place letters from a studied word should still have had a minimal effect on the recognition without identification effect for two reasons. The first is that, as mentioned previously, participants could have assumed that this was a coincidence, and that the letters just corresponded to a different word they could not identify. Furthermore, recognizing fragments as containing out of place letters could have also worked against participants' ability to distinguish between studied and unstudied Relative Position and Transposition fragments. In more standard recognition experiments, there is a well-established phenomenon known as recollection rejection (e.g., Brainerd & Reyna, 2002; Brainerd et al., 2003) or recall to reject (e.g., Rotello & Heit, 2000; Gallo et al., 2006). For example, a person might study a word such as SOFA, and later be shown the word COUCH. Some of the time the person might falsely recognize COUCH, but other times seeing the word COUCH actually triggers memory for the real studied word SOFA. This leads participants to confidently report that the word COUCH was not studied. Something similar could be occurring with the procedure used here. Participants could recognize that a fragment is similar to a studied word, but that the letters are out of place, thus not typing the target word, but since it is not the same as the studied word, they would give it a very low familiarity rating. However, this would mainly lower the familiarity ratings for the Relative Position and Transposition Fragments when they corresponded to studied words, since studying the target words increases the identification rates. However, future experiments could still consider different instructions regarding identification to further clarify this possible issue.

One other possible issue with the experiments could be the role of positional letter frequency. This is the frequency at which letters are most likely to appear in certain positions. For example, the letter E is not a very common first letter for English words, but it is one of the most common second letters (Norvig, 2012). People do have some degree of awareness of what letters are most likely to appear in certain positions (Koriat & Leiblich, 1974). For example, when asked to guess what letter an unrecalled word starts with, people will guess more frequent first letters such as T (Huebert et al., 2023). All of the fragment types contained the same letters, but the positions of those letters did change, along with positional frequency, across the three fragment types. Research has yet to examine how positional frequency might affect or contribute to word familiarity. However, it is possible that positional frequency could affect word familiarity in some way.

Furthermore, there is also the possible issue of bigram frequency, which is the frequency in which two letter sequences occur. For example, the bigram TH is much more common than the bigram AJ (Norvig, 2012). Bigram frequency has also not been investigated with regards to word familiarity. However, it is possible that people also have some awareness of two letter combinations and how frequent they are. How exactly this might affect the familiarity rating discriminability among unidentified fragments is a question for future research, but this could have been an issue for the Transposition fragments. The Slot Specific and Relative Position fragments had the same bigrams, just in different locations. In contrast, since the Transposition fragments were made by swapping the two letters of each bigram in the Slot Specific Condition, this could have resulted in bigrams that were less common.

Both positional frequency and bigram frequency should not have been substantial issues in these experiments. This is because the Fragment Type manipulation occurred during the test blocks and participants still had to distinguish between fragments corresponding to studied words and fragments not corresponding to studied words. For example, say there was a main effect of bigram frequency, and the less frequent bigrams had a lower baseline level of familiarity compared to more frequent bigrams. This could mean that regardless of study status, Transposition fragments would have lower familiarity ratings. This, and positional frequency could possibly relate to some of the main effects of Fragment Type. However, these lower or higher baseline familiarity ratings should not have compromised the main effect of Study Status. If participants used a strategy of giving high or low familiarity ratings to less frequent bigrams, this again could mean that Transposition fragments would receive lower familiarity ratings overall. This still would not explain why participants gave higher familiarity ratings to Transposition fragments corresponding to studied words compared to Transposition fragments not corresponding to studied words. The same could be said for positional frequency differences and Relative Position Fragments. However, this is why, beyond the null interaction, I did not make any direct comparisons between the different studied Fragment Types.

One might wonder why the overall familiarity ratings found across all conditions were on the low end of the spectrum. To be clear, the results did demonstrate that out of position letters can create familiarity-based discriminability among unidentified word fragments, or the recognition without identification effect. This was shown by the main effect of Study Status, where participants gave higher ratings to fragments corresponding to studied words compared to fragments that did not correspond to studied words. The focus in the present study was on this discriminability. However, even though the discriminability characteristic of the recognition without identification effect was occurring across all conditions reported here, the ratings overall were on the low end of the 0 – 10 scale. For example, in Experiment 1, even though participants gave the unidentified Transposition Fragments higher familiarity ratings when they corresponded to a studied word, the mean for unidentified Transposition Fragments corresponding to a studied word was only 1.15 on a zero to ten scale.

Although participants typically do tend to use the lower end of the ratings scale for judging the familiarity of items that they cannot identify (Cleary, 2002; Cleary & Greene, 2000, 2001; Cleary et al., 2016; Ryals & Cleary, 2012), they were even lower than most existing studies in the present experiments. Though speculative, the reason for this low level of baseline familiarity might have been related to the low identification rates across all conditions. Being able to identify only such a small number of words overall in the present study might have led participants to believe that most of the fragments did not correspond to studied words. They might have then set a low criterion and been hesitant to give high familiarity ratings. This possibility is supported by the finding that even familiarity ratings for the Slot Specific Fragments corresponding to studied words had a mean rating of 1.24 in Experiment 1 when analyzing by participants. As noted earlier, the Slot Specific conditions were just replications of prior recognition without identification experiments. When looking at other studies on recognition without identification, the ratings tend to be higher. For example, in Experiment 2B by Cleary and Greene (2000) the mean familiarity ratings for unidentified fragments corresponding to studied words was 4.15. This Experiment was the most similar to the Slot Specific condition in the current Experiments. Thus, out of place letters might create higher familiarity ratings in other contexts.

Moving Toward a Comprehensive Understanding of Letter Position Coding

The present results do speak against both ideas that absolute positions or relative positions are a requirement for the letter matching process to occur. It was important to determine this before moving on to the more comprehensive question of how exactly letter position is matched when producing word familiarity. Based on the current results, the letters of a later encountered unidentified word fragment seem to elicit a recognition without identification effect of the same magnitude regardless of whether the letters are in their absolute positions, relative positions, or have been transposed. As it was predicted that, at the very least, transposed letter fragments should diminish the magnitude of the recognition without identification effect even if not eliminating it altogether, a puzzle concerns the word fragment recognition without identification effect's boundaries. Is there a limit to the flexibility of letter matching? If so, what exactly is that limit? For example, would transposing letters even farther away than was done in the present study result in a reduction in the magnitude of the word fragment recognition without identification effect? Would scrambling all letters of words out of their original positions still lead a word recognition without identification effect, or would that be the boundary condition that leads to its disappearance? Finally, an ongoing question concerns whether there really is no cost to adjacent letters being out of place.

These questions could be answered in future studies that directly compare transpositions of various distances with a much larger sample size and number of trials. Though there was not a cost to letter transpositions in these experiments (the effect of Study Status was not significantly diminished for Transposition Fragments), this could have been related to floor effects for familiarity ratings overall, or to a lack of sufficient power to detect small potential differences in the magnitude of the recognition without identification effect. It also remains possible that the further the letter moves, the less familiarity it will generate. If that is the case, then this would suggest that the theorized letter matching process occurs in a similar manner to the Overlap Model (Gomez et al., 2008), possibly with diminished familiarity-based discriminability among unidentified word fragments the further the letters are from each other.

Such a study could also be computationally modeled to determine the nature of the location flexibility. If there is a small cost across all positions, this would mean that there is plenty of flexibility, and the range of the curves would look similar to Figure 1. In contrast, if the contribution to familiarity does not exist beyond adjacent slots, then the flexibility might be limited to much narrower curves.

An additional experiment that could lead to a more comprehensive understanding of letter position matching would be to examine transpositions across various letter positions. As discussed earlier, Rayner et al. (2007) found that transposing the first letter position slowed down reading more than any of the other letter positions. Rayner et al. also found that transpositions of the last letter position slowed down reading more than the interior positions (also see Johnson & Eisler, 2012). Additionally, Perea & Lupker (2003a, 2003b) found that transpositions occurring at the last letter position were much more detrimental than transpositions occurring for interior letter positions. Finally, although not an investigation of position matching, Huebert and Cleary (2022) found that the first and last letter positions seem to carry more weight in the production of word familiarity. Taken together these results suggest that the flexible position matching does not apply equally to all letter positions. Instead, the first and last letter positions are more rigid. The letter matching mechanism might not try to match up the first and last letters of a test item to any of the other slots. When trying to create a computational model of letter matching that leads to word familiarity, it will be useful to incorporate the known evidence that the first and last letter positions are likely weighted differently and should be modeled differently compared to the interior positions. Specifically, the range of familiarity contribution could be much narrower for the first and last letter positions.

Establishing that the first and last letter positions are not flexible (or are less flexible) could also connect to some related findings. As noted earlier, the first and last letter positions seem to contribute more to word familiarity compared to the interior positions (Huebert & Cleary, 2022). This could be because the first and last letter positions each have one letter adjacent to them, while interior letters are adjacent to two letters each. Thus, Huebert and Cleary argued that the first and last letter positions might be especially important because they do not receive the same amount of interference from adjacent letters as the interior letters do. Something similar could certainly be at play if there are different levels of flexibility in letter position matching. Perhaps because the first and last letter positions have empty space next to them, it is easier for people to determine their location or match up their location. Future research could investigate this possibility.

The current results, and the above future directions, could also establish an important finding with regard to familiarity more broadly. This finding is that it seems to be difficult to completely diminish familiarity-based discrimination, as seen by the significant main effect of Study Status in both experiments. Even changing the positions of the letters from study to test still produced a difference in familiarity ratings. This is not to say that letter transpositions will never have an effect, as discussed previously, far away transpositions could lead to no ability to detect familiarity. However, at the very least, nearby transpositions seem to still allow for familiarity detection. The finding that the feature matching mechanism is at least somewhat flexible also suggests that it is not easily disrupted. This could certainly have negative effects, such as leading to the various forms of false recognition described earlier. However, this could also be a positive in some ways. Our stimuli are constantly changing, a person might introduce themselves more formally by their full name, while they might use a shortened name in more casual circumstances. For example, consider someone formally introduced as REBECCA but who goes by BECCA or BECK. These names do not match up from a slot specific approach, but they might match up with a more flexible letter matching mechanism. It could be useful for a familiarity mechanism to be able to generate familiarity with the altered name. This could be similar to how it is useful for people to be able to read words with unintended transposition related mistakes in them. It could even be useful for people to be able to recognize that they have seen a written name before that contains spelling mistakes such as a transposition.

It is not possible to answer all of these questions in a single set of experiments. However, these experiments do take a strong first step in understanding how letter matching works. These experiments also open up many possibilities for future experiments to better explain more broadly how the feature matching mechanism works. With several future investigations, there should be a much clearer understanding of how feature location is coded and matched. However, these experiments should be a strong step in the direction of understanding how we match up features and detect familiarity.

Broader Implications

At a broader level, the current findings have implications for the nature of the feature matching process that produces familiarity detection. All of the studies discussed in this dissertation have made extraordinary steps in identifying features that can contribute to familiarity detection for various types of stimuli. However, all of these studies, other than Kostic and Cleary (2009), generally only considered whether a feature was present or absent. The current results suggest it might not be so simple. A feature might be in the right location, close to the right location, or far from the correct location. Thus, feature matching is not just an issue of whether a certain feature is present or not, but how close the feature is to the proper location.

The current results also have a lot of potential implications for stimuli other than just words. Perhaps the most relevant might be scene familiarity. When a scene feels familiar this is most likely because it has feature overlap with a previously encountered scene. There could be many features involved in this process but overlapping objects could certainly be a relevant feature.

An open question is how the process of matching item locations works in scene familiarity, and thus, where those objects need to be in the later scene to produce familiarity detection. Just like with words, one possibility is that the objects must be in the same location between study and test. Another possibility is that the objects must be near where a similar object was studied. Those objects do not need to be in the exact same locations, nor do they need to be in the same relative locations. As one example, consider a person entering an office that contains a desk, chairs, and magazines. How are the locations of these objects coded? Based on the results of this dissertation, those objects do not need to be in the same location as they were initially encountered to create a sense of familiarity or to recognize the office. The magazines could be moved to a different table, the chairs could be moved and so on. Future research should consider systematic ways of investigating such a question. Finding that out of place objects still contribute to scene familiarity would reveal something about the nature of the feature matching process. The feature matching mechanism does not simply try to match a given object to the exact same location it was studied. Instead, the mechanism is more flexible and will try to match that object or feature up with multiple locations around the room.

Similar to words, it could also be useful to determine that the mechanism behind scene familiarity is not easily broken. A scene could certainly change from one encounter to another. Furniture could be moved; objects could be relocated. This could be another case where it would be useful for the familiarity mechanism to be somewhat flexible in the feature matching process and for familiarity detection to not easily be broken. In contrast, if someone entered a room where moving some of the objects did not lead to any sense of familiarity or familiarity with the recall of specifics, they might fail to recognize a common place with some alterations.

Furthermore, future research should also consider how to investigate such a question with regard to déjà vu. Déjà vu is a unique type of familiarity detection where the person feels that something feels familiar, even though the person realizes it should not feel familiar (Brown, 2003; Schwartz & Cleary, 2016). Consider again a person entering an office for the first time. That office might contain very similar objects as a different office that the person has been to. The person might get a strong sense of familiarity from the similarity of the two offices, but rationally they know they have never been to the current office before. This similarity could be driven by the overlapping objects. Again, how are the locations of these objects coded? Do they need to be in the same locations between the two offices? The current results would suggest they might just need to be near the same locations. Thus, the issue of how object locations are coded into memory that potentially leads to déjà vu is an open question as well.

The present results could also have implications for the false recognition of scenes or environments. Consider a person walking around a place they have not been to for a number of years. The person might be trying to get back to their hotel which is near a certain building. What buildings and surrounding areas might be falsely recognized? If the correct building had a grassy area to the left and a car parked in front, how are the locations of these objects coded into memory? Would a person falsely recognize a different building that had a car parked to the left and a grassy area in front? The present results suggest that they might indeed recognize the wrong building, even if the matching features are not in the same locations as they were studied.

The present results also have implications for music recognition and familiarity. As discussed earlier, Kostic and Cleary (2009) argued that musical features are coded in terms of relativity and not absolute location. This was based off the finding that altering the tempo of the notes still showed a familiarity effect. This meant participants giving higher familiarity ratings to unidentified song fragments when they corresponded to studied songs than when they did not correspond to studied songs. In contrast, scrambling the order of the notes did not produce a familiarity effect. The authors argued that relativity was maintained when tempo changed, but disrupted when the order of the notes was changed. Thus, musical features seem to be coded in terms of relativity to each other.

The present results do not rule out this theory, but they do warrant further investigation. As also discussed earlier, Kostic and Cleary (2009) did not report the distance of the note transpositions. The current experiments showed familiarity effects for adjacent transpositions. The next question is if further transpositions would still produce a familiarity signal. Based on the Overlap Model (Gomez et al., 2008), the further away a letter is from the correct position, the less activation it will cause. The same could also be true for creating a familiarity signal. It could have been the case that most of the note transpositions by Kostic and Cleary were not adjacent transpositions and were much farther. Thus, the notes were too far from their original positions for familiarity to be produced. Alternatively, it is possible that musical feature location is somehow coded in a different way than letter location. Future research could investigate this by only using nearby transpositions of notes.

Future Directions

The present results could have implications for human memory processes as studied using other memory paradigms, as well as for the lexical processes as studied using paradigms from psycholinguistics. For example, the results could also have implications for falsely recognizing various forms of text as mentioned earlier. For example, if a person read that they were supposed to take a turn at a certain street sign, what street signs might the person wrongly recognize as the street where they are supposed to turn? Based on the current findings, the person might have a sense of familiarity with other streets that share the same letters as the target street, even if those letters are out of both slot specific and relative positions. For example, if the actual target street was PARMY, streets such as PRAYM could be wrongly recognized. This would not just be because of the overlapping P in the first letter position. Even though PRAYM street has the same letters out of both slot specific and relative position, they could very much produce a detectable familiarity signal leading to a sense of familiarity.

The results also have implications for the matching of letters between words of different lengths. Van Assche and Grainger (2006) found significant priming effects when the prime was longer than the target word. For example, the authors would use primes with a repeated letter (e.g., JUSSTICE) for a target such as JUSTICE, or identity primes that were the same as the targets. From a slot specific approach (e.g., McClelland & Rumelhart, 1981; Rumelhart & McClelland, 1982; Coltheart et al., 1993; Coltheart et al., 2001; Zorzi et al., 1998), the identity prime matches up much better with the target than the repeated letter prime. Yet, these identity primes did not reduce lexical decision time any more than the identity primes did.

Something similar could certainly apply to word familiarity and false word recognition. Once again, if there is flexibility in the letter matching process, then nonmatching word lengths might not be an issue. Consider two hypothetical street names like TLEMINS and TEMIN. Could these two names be confused when presented on street signs? From a slot specific perspective, only the first letter T would contribute to the false recognition. This is because the first letter overlaps in the first letter position. All of the other letters do not line up in terms of absolute slot specific positions. In contrast, from an overlap perspective and the results found here, the two street names are quite similar, and one could easily be falsely recognized. If the locations of letters such as E,M,I,N are coded as general locations, then they overlap between the two street names.

Another important future direction is to investigate how location is coded with regard to both orthography, the visual shape of words, and phonology, the sound that words produce. As discussed in the introduction, word familiarity occurs through the matching of overlapping features between study and test (Clark & Gronlund, 1996). In the case of word familiarity, one contributor is of course overlapping letters. However, letters contain both orthography and phonology. In one experiment, Cleary (2004) had participants study words that had similar phonology but different orthography (e.g., RAFT and LAUGHED). Cleary did find a recognition without cued recall effect here, but it was smaller compared to when both orthography and phonology overlapped (e.g., CHEETAH and CHEETHOH). This suggests that both orthography and phonology can contribute to word familiarity when dealing with printed words.

Thus, when out of position letters still contribute to a familiarity signal, what is driving this? Is it the orthography of the letters, the phonology of the letters, or both? This could be investigated by using a similar procedure as Cleary and Greene (2000), where participants listened to spoken words at study, and then fragments were presented on a computer screen at test. The reverse could also be done where participants read word fragments during study, but then listen to words at test.

Aside from attempting to separate the contributions of orthography and phonology, future research could also examine how feature location is coded more strictly for spoken word familiarity. Indeed, acoustic recognition without identification has been demonstrated (Cleary et al., 2007). Furthermore, transposition priming has also been demonstrated using auditory primes and auditory lexical decision (e.g., Dufour & Grainger, 2019; Dufour et al., 2023). Thus, future research could follow the same procedure as was done here but using only spoken words and word fragments.

Concluding Remarks

One could ask why the current studies are limited to familiarity detection or the feeling of recognition without recalling specifics, instead of looking more broadly at recognition that might occur *with* the recall of specifics. There were a number of reasons for this. The first reason is that the parallels between word reading, and word familiarity might be specific to familiarity detection in the absence of recall. For example, the finding that the first and last letter positions are special in word reading extends to word familiarity (Huebert & Cleary, 2022). There does not seem to be any research specifically demonstrating that the first and last letter positions also play a key role in recalling specifics. It is certainly possible that they do carry a special role, but it was safer to start with what is more well supported in the literature on familiarity without recalling specifics. Furthermore, there have been many dissociations found between recall and familiarity, where a certain variable might affect recall and not familiarity, or vice versa (see Yonelinas, 2002, for a review). However, future research could certainly investigate whether out of place letters can contribute to recognition memory when people do feel like they can recall specifics.

It is also worth noting that there is growing research on how familiarity detection might play a bigger role in cognition than was previously thought. Many dual process models assume that familiarity detection acts as more of a backup system to recalling specifics (see Yonelinas, 2002 for a review). Since the feeling of familiarity is more error prone, some (e.g., Yonelinas et al., 2010) would argue that familiarity is only used when recalling specifics fails.

However, more recent research has suggested that it might work differently. Instead, an initial feeling of familiarity might lead people to turn their attention inward and search for recollective details (Cleary et al., 2023). This is supported by the finding that people tend to report more incorrect recollective details as familiarity increases (Carlaw et al., 2022; McNeely-White & Cleary, 2023). Thus, what might ultimately end up as the recall of specifics may have initially been driven by a sense of familiarity. Furthermore, familiarity detection can also lead to the subjective experience of recalling details, even when those details are mere guesses (Huebert et al., 2022). Overall, though the feeling of familiarity might at times be a secondary or fallback form of recognition to recalling specifics, it might play a larger role in human cognition. Thus, it is important to understand how familiarity is generated.

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APPENDIX A

The power analysis was based off of Perea and Lupker (2003a). These authors compared the effects of transposition primes to replacement and identity primes. Their experiments were lexical decision and priming whereas the proposed experiments involve recognition memory judgments. However, they are the only experiments to base a power analysis on. Of all of their analyses, the smallest one had an effect size of η_p^2 = .21. This was the interaction between related primes and unrelated control primes and whether the prime contained a transposition. Inputting this effect size into G power (Faul et al., 2007), with a significance level of .001, and a power level of .999 gave a recommendation of 37 participants. However, given that Perea and Lupker used a very different task than I will use in the proposed experiments, I used 48 participants to err on the side of caution. This also meant an even number of eight participants in each of the six versions.

APPENDIX B

Target	Block	Slot Specific Fragments	Relative Position Fragments	Transposition Fragments
ADVANTAGE	1	_DV_ _ _AG_	_ _DV_AG_ _	_VD_ _ _GA_
ADVERSITY	1	_DV_ _ _IT_	_ _DV_TI_ _	_VD_ _ _IT_
AGONIZING	1	_GO_ _ _IN_	_ _GO_IN_ _	_OG_ _ _NI_
AIRPOCKET	1	_IR_ _ _KE_	_ _IR_KE_ _	_RI_ _ _EK_
AUTOGRAPH	1	_UT_ _ _AP_	_ _UT_AP_ _	_TU_ _ _PA_
CLAVICLES	1	_LA_ _ _LE_	_ _LA_LE_ _	_AL_ _ _EL_
DEVELOPER	1	_EV_ _ _PE_	_ _EV_PE_ _	_VE_ _ _EP_
DISTURBER	1	_IS_ _ _BE_	_ _IS_BE_ _	_SI_ _ _EB_
ELUSIVLEY	1	_LU_ _ _LE_	_ _LU_LE_ _	_UL_ _ _EL_
ENERGIZER	1	_NE_ _ _ZE_	_ _NE_ZE_ _	_EN_ _ _EZ_
FANTASTIC	1	_AN_ _ _TI_	_ _AN_TI_ _	_NA_ _ _IT_
HAMSTRING	1	_AM_ _ _IN_	_ _AM_IN_ _	_MA_ _ _NI_
IMPORTANT	1	_MP_ _ _AN_	_ _MP_AN_ _	_PM_ _ _NA_
LUBRICATE	1	_UB_ _ _AT_	_ _UB_AT_ _	_BU_ _ _TA_
MATERNITY	1	_AT_ _ _IT_	_ _AT_IT_ _	_TA_ _ _TI_
MATRIMONY	1	_AT_ _ _ON_	_ _AT_ON_ _	_TA_ _ _NO_
MISPLACED	1	_IS_ _ _CE_	_ _IS_CE_ _	_SI_ _ _EC_
NORMALISE	1	_OR_ _ _IS_	_ _OR_IS_ _	_RO_ _ _SI_
PROFANITY	1	_RO_ _ _IT_	_ _RO_IT_ _	_OR_ _ _TI_
PROMINENT	1	_RO_ _ _EN_	_ _RO_EN_ _	_OR_ _ _NE_
SKYROCKET	1	_KY_ _ _KE_	_ _KY_KE_ _	_YK_ _ _EK_
SPACEPORT	1	_PA_ _ _OR_	_ _PA_OR_ _	_AP_ _ _RO_
SPINELESS	1	_PI_ _ _ES_	_ _PI_ES_ _	_IP_ _ _SE_
SUPERNOVA	1	_UP_ _ _OV_	_ _UP_OV_ _	_PU_ _ _VO_
TALKATIVE	1	_AL_ _ _IV_	_ _AL_IV_ _	_LA_ _ _VI_
TYPEWRITE	1	_YP_ _ _IT_	_ _YP_IT_ _	_PY_ _ _TI_

UNDERTAKE	1	_ND_ _ _AK_	_ _ND_AK_ _	_DN_ _ _KA_
VEGETABLE	1	_EG_ _ _BL_	_ _EG_BL_ _	_GE_ _ _LB_
VULGARITY	1	_UL_ _ _IT_	_ _UL_IT_ _	_LU_ _ _TI_
WASTELAND	1	_AS_ _ _AN_	_ _AS_AN_ _	_SA_ _ _NA_
ACADEMICS	2	_CA_ _ _IC_	_ _CA_IC_ _	_AC_ _ _CI_
ADVERSITY	2	_DV_ _ _IT_	_ _DV_IT_ _	_VD_ _ _TI_
AEROSPACE	2	_ER_ _ _AC_	_ _ER_AC_ _	_RE_ _ _CA_
AWKWARDLY	2	_WK_ _ _DL_	_ _WK_DL_ _	_KW_ _ _LD_
BACKPEDAL	2	_AC_ _ _DA_	_ _AC_DA_ _	_CA_ _ _AD_
CABDRIVER	2	_AB_ _ _VE_	_ _AB_VE_ _	_BA_ _ _EV_
CONVOLUTE	2	_ON_ _ _UT_	_ _ON_UT_ _	_NO_ _ _TU_
CORPUSCLE	2	_OR_ _ _CL_	_ _OR_CL_ _	_RO_ _ _LC_
DECIMATES	2	_EC_ _ _TE_	_ _EC_TE_ _	_CE_ _ _ET_
DEPENDENT	2	_EP_ _ _EN_	_ _EP_EN_ _	_PE_ _ _NE_
DISEMBODY	2	_IS_ _ _OD_	_ _IS_OD_ _	_SI_ _ _DO_
ESCAPABLE	2	_SC_ _ _BL_	_ _SC_BL_ _	_CS_ _ _LB_
EXHUSBAND	2	_XH_ _ _AN_	_ _XH_AN_ _	_HX_ _ _NA_
FORGETFUL	2	_OR_ _ _FU_	_ _OR_FU_ _	_RO_ _ _UF_
HYPNOTIST	2	_YP_ _ _IS_	_ _YP_IS_ _	_PY_ _ _SI_
INTROVERT	2	_NT_ _ _ER_	_ _NT_ER_ _	_TN_ _ _RE_
NEVERMIND	2	_EV_ _ _IN_	_ _EV_IN_ _	_VE_ _ _NI_
OBJECTIFY	2	_BJ_ _ _IF_	_ _BJ_IF_ _	_JB_ _ _FI_
OVERDRESS	2	_VE_ _ _ES_	_ _VE_ES_ _	_EV_ _ _SE_
SACRIFICE	2	_AC_ _ _IC_	_ _AC_IC_ _	_CA_ _ _CI_
SOCIALIST	2	_OC_ _ _IS_	_ _OC_SI_ _	_CO_ _ _SI_
SPRIRITUAL	2	_PR_ _ _TU_	_ _PR_TU_ _	_RP_ _ _UT_
TRANSLATE	2	_RA_ _ _AT_	_ _RA_AT_ _	_AR_ _ _TA_
ULTIMATUM	2	_LT_ _ _TU_	_ _LT_TU_ _	_TL_ _ _UT_
UMBILICAL	2	_MB_ _ _CA_	_ _MB_CA_ _	_BM_ _ _AC_

UNBUCKLED	2	_NB_ _ _LE_	_ _NB_LE_ _	_BN_ _ _EL_
UNDERDONE	2	_ND_ _ _ON_	_ _ND_ON_ _	_DN_ _ _NO_
WHIRLWIND	2	_HI_ _ _IN_	_ _HI_IN_ _	_IH_ _ _NI_
WOLVERINE	2	_OL_ _ _IN_	_ _OL_IN_ _	_LO_ _ _NI_
WORKBENCH	2	_OR_ _ _NC_	_ _OR_NC_ _	_RO_ _ _CN_
CAPTIVITY	3	_AP_ _ _IT_	_ _AP_IT_ _	_PA_ _ _TI_
ELECTRIFY	3	_LE_ _ _IF_	_ _LE_IF_ _	_EL_ _ _FI_
HASTINESS	3	_AS_ _ _ES_	_ _AS_ES_ _	_SA_ _ _SE_
HOMOGRAPH	3	_OM_ _ _AP_	_ _OM_AP_ _	_MO_ _ _PA_
HYDRATING	3	_YD_ _ _IN_	_ _YD_IN_ _	_DY_ _ _NI_
HYPERBOLE	3	_YP_ _ _OL_	_ _YP_OL_ _	_PY_ _ _LO_
IMAGINARY	3	_MA_ _ _AR_	_ _MA_AR_ _	_AM_ _ _RA_
INTERPRET	3	_NT_ _ _RE_	_ _NT_RE_ _	_TN_ _ _ER_
LAZYBONES	3	_AZ_ _ _NE_	_ _AZ_NE_ _	_ZA_ _ _EN_
MANDATORY	3	_AN_ _ _OR_	_ _AN_OR_ _	_NA_ _ _RO_
MODERATOR	3	_OD_ _ _TO_	_ _OD_TO_ _	_DO_ _ _OT_
MUNICIPAL	3	_UN_ _ _PA_	_ _UN_PA_ _	_NU_ _ _AP_
NEGLIGENT	3	_EG_ _ _EN_	_ _EG_EN_ _	_GE_ _ _NE_
NOSTALGIA	3	_OS_ _ _GI_	_ _OS_GI_ _	_SO_ _ _IG_
NUMERATOR	3	_UM_ _ _TO_	_ _UM_TO_ _	_MU_ _ _OT_
PHONOLOGY	3	_HO_ _ _OG_	_ _HO_OG_ _	_OH_ _ _GO_
PRINCIPAL	3	_RI_ _ _PA_	_ _RI_PA_ _	_IR_ _ _AP_
PROTOTYPE	3	_RO_ _ _YP_	_ _RO_YP_ _	_OR_ _ _PY_
QUADRICEP	3	_UA_ _ _CE_	_ _UA_CE_ _	_AU_ _ _EC_
RIVERBANK	3	_IV_ _ _AN_	_ _IV_AN_ _	_VI_ _ _NA_
SHARKSKIN	3	_HA_ _ _KI_	_ _HA_KI_ _	_AH_ _ _IK_
SHORTSTOP	3	_HO_ _ _TO_	_ _HO_TO_ _	_OH_ _ _OT_
STORYLINE	3	_TO_ _ _IN_	_ _TO_IN_ _	_OT_ _ _NI_
TARANTULA	3	_AR_ _ _UL_	_ _AR_UL_ _	_RA_ _ _LU_

TRANSFUSE	3	_RA_ _ _US_	_ _RA_US_ _	_AR_ _ _SU_
VICTIMIZE	3	_IC_ _ _IZ_	_ _IC_IZ_	_CI_ _ _ZI_
WATERFALL	3	_AT_ _ _AL_	_ _AT_AL_ _	_TA_ _ _LA_
WHOLESALE	3	_HO_ _ _AL_	_ _HO_AL_ _	_OH_ _ _LA_
WIKIPEDIA	3	_IK_ _ _DI_	_ _IK_DI_ _	_KI_ _ _ID_
WINEGLASS	3	_IN_ _ _AS_	_ _IN_AS_ _	_NI_ _ _SA_
ABDOMINAL	4	_BD_ _ _NA_	_ _BD_NA_ _	_DB_ _ _AN_
ACTIVISTS	4	_CT_ _ _ST_	_ _CT_ST_ _	_TC_ _ _TS_
ADJACENCY	4	_DJ_ _ _NC_	_ _DJ_NC_ _	_JD_ _ _CN_
ADRENALIN	4	_DR_ _ _LI_	_ _DR_LI_ _	_RD_ _ _IL_
AESTETIC	4	_ES_ _ _IC_	_ _ES_IC_ _	_SE_ _ _CI_
ALCOHOLIC	4	_LC_ _ _LI_	_ _LC_LI_ _	_CL_ _ _IL_
ASTROLOGY	4	_ST_ _ _OG_	_ _ST_OG_ _	_TS_ _ _GO_
DIPLOMACY	4	_IP_ _ _AC_	_ _IP_AC_ _	_PI_ _ _CA_
FERTILITY	4	_ER_ _ _IT_	_ _ER_IT_ _	_RE_ _ _TI_
FLAPJACKS	4	_LA_ _ _CK_	_ _LA_CK_ _	_AL_ _ _KC_
GODPARENT	4	_OD_ _ _EN_	_ _OD_EN_ _	_DO_ _ _NE_
IBUPROFEN	4	_BU_ _ _FE_	_ _BU_FE_ _	_UB_ _ _EF_
INVALIDLY	4	_NV_ _ _DL_	_ _NV_DL_ _	_VN_ _ _LD_
MELATONIN	4	_EL_ _ _NI_	_ _EL_NI_ _	_LE_ _ _IN_
MUSCLEMEN	4	_US_ _ _ME_	_ _US_ME_ _	_SU_ _ _EM_
NAVIGATOR	4	_AV_ _ _TO_	_ _AV_TO_ _	_VA_ _ _OT_
NOTEPAPER	4	_OT_ _ _PE_	_ _OT_PE_ _	_TO_ _ _EP_
OUTNUMBER	4	_UT_ _ _BE_	_ _UT_BE_ _	_TU_ _ _EB_
PARALEGAL	4	_AR_ _ _GA_	_ _AR_GA_ _	_RA_ _ _AG_
POLITICAL	4	_OL_ _ _CA_	_ _OL_CA_ _	_LO_ _ _AC_
RADIOGRAM	4	_AD_ _ _RA_	_ _AD_RA_ _	_DA_ _ _AR_
SCAVENGER	4	_CA_ _ _GE_	_ _CA_GE_ _	_AC_ _ _EG_
SIGNATURE	4	_IG_ _ _UR_	_ _IG_UR_ _	_GI_ _ _RU_

SMALLTIME	4	_MA_ _ _IM_	_ _MA_IM_ _	_AM_ _ _MI_
SNAKESKIN	4	_NA_ _ _KI_	_ _NA_KI_ _	_AN_ _ _IK_
SPOKESMAN	4	_PO_ _ _MA_	_ _PO_MA_ _	_OP_ _ _AM_
SUNSTROKE	4	_UN_ _ _OK_	_ _UN_OK_ _	_NU_ _ _KO_
TAXIDERMY	4	_AX_ _ _RM_	_ _AX_RM_ _	_XA_ _ _MR_
WEDNESDAY	4	_ED_ _ _DA_	_ _ED_DA_ _	_DE_ _ _AD_
ZINFANDEL	4	_IN_ _ _DE_	_ _IN_DE_ _	_NI_ _ _ED_

APPENDIX C

Target	Block	Slot Specific Fragments	Relative Position Fragments	Transposition Fragments
ACTIVISTS	1	_ _TI_IS_ _	_TI_ _ _IS_	_ _IT_SI_ _
ADVANTAGE	1	_ _VA_TA_ _	_VA_ _ _TA_	_ _AV_AT_ _
AEROSPACE	1	_ _RO_PA_ _	_RO_ _ _PA_	_ _OR_AP_ _
AESTETICS	1	_ _ST_TI_ _	_ST_ _ _TI_	_ _TS_IT_ _
AGONIZING	1	_ _ON_ZI_ _	_ON_ _ _ZI_	_ _NO_IZ_ _
ALCOHOLIC	1	_ _CO_OL_ _	_CO_ _ _OL_	_ _OC_LO_ _
BACKPEDAL	1	_ _CK_ED_ _	_CK_ _ _ED_	_ _KC_DE_ _
DEPENDENT	1	_ _PE_DE_ _	_PE_ _ _DE_	_ _EP_ED_ _
DEVELOPER	1	_ _VE_OP_ _	_VE_ _ _OP_	_ _EV_PO_ _
EXHUSBAND	1	_ _HU_BA_ _	_HU_ _ _BA_	_ _UH_AB_ _
GODPARENT	1	_ _DP_RE_ _	_DP_ _ _RE_	_ _PD_ER_ _
HAMSTRING	1	_ _MS_RI_ _	_MS_ _ _RI_	_ _SM_IR_ _
INTROVERT	1	_ _TR_VE_ _	_TR_ _ _VE_	_ _RT_EV_ _
LAZYBONES	1	_ _ZY_ON_ _	_ZY_ _ _ON_	_ _YZ_NO_ _
LUBRICATE	1	_ _BR_CA_ _	_BR_ _ _CA_	_ _RB_AC_ _
MUNICIPAL	1	_ _NI_IP_ _	_NI_ _ _IP_	_ _IN_ PI_ _
NOSTALGIA	1	_ _ST_LG_ _	_ST_ _ _LG_	_ _TS_GL_ _
PRINCIPAL	1	_ _IN_IP_ _	_IN_ _ _IP_	_ _NI_PI_ _
REPLICATE	1	_ _PL_CA_ _	_PL_ _ _CA_	_ _LP_AC_ _
SNAKESKIN	1	_ _AK_SK_ _	_AK_ _ _SK_	_ _KA_KS_ _
SUNSTROKE	1	_ _NS_RO_ _	_NS_ _ _RO_	_ _SN_OR_ _
TAXIDERMY	1	_ _XI_ER_ _	_XI_ _ _ER_	_ _IX_RE_ _
ULTIMATUM	1	_ _TI_AT_ _	_TI_ _ _AT_	_ _IT_TA_ _
UNBUCKLED	1	_ _BU_KL_ _	_BU_ _ _KL_	_ _UB_LK_ _

UNDERDONE	1	_ _DE_DO_ _	_DE_ _ _DO_	_ _ED_OD_ _
UNDERTAKE	1	_ _DE_TA_ _	_DE_ _ _TA_	_ _ED_AT_ _
VICTIMIZE	1	_ _CT_MI_ _	_CT_ _ _MI_	_ _TC_IM_ _
WARMONGER	1	_ _RM_NG_ _	_RM_ _ _NG_	_ _MR_GN_ _
WASTELAND	1	_ _ST_LA_ _	_ST_ _ _LA_	_ _TS_AL_ _
WOLVERINE	1	_ _LV_RI_ _	_LV_ _ _RI_	_ _VL_IR_ _
ACADEMICS	2	_ _AD_MI_ _	_AD_ _ _MI_	_ _DA_IM_ _
ASTROLOGY	2	_ _TR_LO_ _	_TR_ _ _LO_	_ _RT_OL_ _
DECIMATES	2	_ _CI_AT_ _	_CI_ _ _AT_	_ _IC_TA_ _
DIPLOMACY	2	_ _PL_MA_ _	_PL_ _ _MA_	_ _LP_AM_ _
DISEMBODY	2	_ _SE_BO_ _	_SE_ _ _BO_	_ _ES_OB_ _
HOMOGRAPH	2	_ _MO_RA_ _	_MO_ _ _RA_	_ _OM_AR_ _
ILLOGICAL	2	_ _LO_IC_ _	_LO_ _ _IC_	_ _OL_CI_ _
IMAGINARY	2	_ _AG_NA_ _	_AG_ _ _NA_	_ _GA_AN_ _
MANDATORY	2	_ _ND_TO_ _	_ND_ _ _TO_	_ _DN_OT_ _
MATRIMONY	2	_ _TR_MO_ _	_TR_ _ _MO_	_ _RT_OM_ _
MISPLACED	2	_ _SP_AC_ _	_SP_ _ _AC_	_ _PS_CA_ _
MUSCLEMEN	2	_ _SC_EM_ _	_SC_ _ _EM_	_ _CS_ME_ _
NUMERATOR	2	_ _ME_AT_ _	_ME_ _ _AT_	_ _EM_TA_ _
OBJECTIFY	2	_ _JE_TI_ _	_JE_ _ _TI_	_ _EJ_IT_ _
REALISTIC	2	_ _AL_ST_ _	_AL_ _ _ST_	_ _LA_TS_ _
RIVERBANK	2	_ _VE_BA_ _	_VE_ _ _BA_	_ _EV_AB_ _
SCAVENGER	2	_ _AV_NG_ _	_AV_ _ _NG_	_ _VA_GN_ _
SKYROCKET	2	_ _YR_CK_ _	_YR_ _ _CK_	_ _RY_KC_ _
SMALLTIME	2	_ _AL_TI_ _	_AL_ _ _TI_	_ _LA_IT_ _
SPOKESMAN	2	_ _OK_SM_ _	_OK_ _ _SM_	_ _KO_MS_ _
STOCKYARD	2	_ _OC_YA_ _	_OC_ _ _YA_	_ _CO_AY_ _
STORYLINE	2	_ _OR_LI_ _	_OR_ _ _LI_	_ _RO_IL_ _

SUPERNOVA	2	_ _PE_NO_ _	_PE_ _ _NO_	_ _EP_ON_ _
TALKATIVE	2	_ _LK_TI_ _	_LK_ _ _TI_	_ _KL_IT_ _
TRANSFUSE	2	_ _AN_FU_ _	_AN_ _ _FU_	_ _NA_UF_ _
TYPEWRITE	2	_ _PE_RI_ _	_PE_ _ _RI_	_ _EP_IR_ _
VEGETABLE	2	_ _GE_AB_ _	_GE_ _ _AB_	_ _EG_BA_ _
VULGARITY	2	_ _LG_RI_ _	_LG_ _ _RI_	_ _GL_IR_ _
WHOLESALE	2	_ _OL_SA_ _	_OL_ _ _SA_	_ _LO_AS_ _
ZINFANDEL	2	_ _NF_ND_ _	_NF_ _ _ND_	_ _FN_DN_ _
ABDOMINAL	3	_ _DO_IN_ _	_DO_ _ _IN_	_ _OD_NI_ _
ADRENALIN	3	_ _RE_AL_ _	_RE_ _ _AL_	_ _ER_LA_ _
AIRPOCKET	3	_ _RP_CK_ _	_RP_ _ _CK_	_ _PR_KC_ _
CABDRIVER	3	_ _BD_IV_ _	_BD_ _ _IV_	_ _DB_VI_ _
COCKFIGHT	3	_ _CK_IG_ _	_CK_ _ _IG_	_ _KC_GI_ _
CONVOLUTE	3	_ _NV_LU_ _	_NV_ _ _LU_	_ _VN_UL_ _
ELECTRIFY	3	_ _EC_RI_ _	_EC_ _ _RI_	_ _CE_IR_ _
FANTASTIC	3	_ _NT_ST_ _	_NT_ _ _ST_	_ _TN_TS_ _
FERTILITY	3	_ _RT_LI_ _	_RT_ _ _LI_	_ _TR_IL_ _
FORGETFUL	3	_ _RG_TF_ _	_RG_ _ _TF_	_ _GR_FT_ _
HASTINESS	3	_ _ST_NE_ _	_ST_ _ _NE_	_ _TS_EN_ _
INTERPRET	3	_ _TE_PR_ _	_TE_ _ _PR_	_ _ET_RP_ _
INVALIDLY	3	_ _VA_ID_ _	_VA_ _ _ID_	_ _AV_DI_ _
MELATONIN	3	_ _LA_ON_ _	_LA_ _ _ON_	_ _AL_NO_ _
MODERATOR	3	_ _DE_AT_ _	_DE_ _ _AT_	_ _ED_TA_ _
NEOCORTEX	3	_ _OC_RT_ _	_OC_ _ _RT_	_ _CO_TR_ _
NEVERMIND	3	_ _VE_MI_ _	_VE_ _ _MI_	_ _EV_IM_ _
NOTEPAPER	3	_ _TE_AP_ _	_TE_ _ _AP_	_ _ET_PA_ _
PROTOTYPE	3	_ _OT_TY_ _	_OT_ _ _TY_	_ _TO_YT_ _
QUADRICEP	3	_ _AD_IC_ _	_AD_ _ _IC_	_ _DA_CI_ _

RADIOGRAM	3	_ _DI_GR_ _	_DI_ _ _GR_	_ _ID_RG_ _
SACRIFICE	3	_ _CR_FI_ _	_CR_ _ _FI_	_ _RC_IF_ _
SEMICOLON	3	_ _MI_OL_ _	_MI_ _ _OL_	_ _IM_LO_ _
SHORTSTOP	3	_ _OR_ST_ _	_OR_ _ _ST_	_ _RO_TS_ _
SOCIALIST	3	_ _CI_LI_ _	_CI_ _ _LI_	_ _IC_IL_ _
SPACEPORT	3	_ _AC_PO_ _	_AC_ _ _PO_	_ _CA_OP_ _
TARANTULA	3	_ _RA_TU_ _	_RA_ _ _TU_	_ _AR_UT_ _
UMBILICAL	3	_ _BI_IC_ _	_BI_ _ _IC_	_ _IB_CI_ _
WEDNESDAY	3	_ _DN_SD_ _	_DN_ _ _SD_	_ _ND_DS_ _
WORKBENCH	3	_ _RK_EN_ _	_RK_ _ _EN_	_ _KR_NE_ _
ADJACENCY	4	_ _JA_EN_ _	_JA_ _ _EN_	_ _AJ_NE_ _
ADVERSITY	4	_ _VE_SI_ _	_VE_ _ _SI_	_ _EV_IS_ _
AUTOGRAPH	4	_ _TO_RA_ _	_TO_ _ _RA_	_ _OT_AR_ _
AWKWARDLY	4	_ _KW_RD_ _	_KW_ _ _RD_	_ _WK_DR_ _
CAPTIVITY	4	_ _PT_VI_ _	_PT_ _ _VI_	_ _TP_IV_ _
CLAVICLES	4	_ _AV_CL_ _	_AV_ _ _CL_	_ _VA_LC_ _
DISTURBER	4	_ _ST_RB_ _	_ST_ _ _RB_	_ _TS_BR_ _
ELUSIVLEY	4	_ _US_VL_ _	_US_ _ _VL_	_ _SU_LV_ _
ENERGIZER	4	_ _ER_IZ_ _	_ER_ _ _IZ_	_ _RE_ZI_ _
ESCAPABLE	4	_ _CA_AB_ _	_CA_ _ _AB_	_ _AC_BA_ _
HYDRATING	4	_ _DR_TI_ _	_DR_ _ _ TI_	_ _RD_IT_ _
HYPERBOLE	4	_ _PE_BO_ _	_PE_ _ _ BO_	_ _EP_OB_ _
IBUPROFEN	4	_ _UP_OF_ _	_UP_ _ _OF_	_ _PU_FO_ _
IMPORTANT	4	_ _PO_TA_ _	_PO_ _ _TA_	_ _OP_AT_ _
MATERNITY	4	_ _TE_NI_ _	_TE_ _ _NI_	_ _ET_IN_ _
NAVIGATOR	4	_ _VI_AT_ _	_VI_ _ _AT_	_ _IV_TA_ _
NEGLIGENT	4	_ _GL_GE_ _	_GL_ _ _GE_	_ _LG_EG_ _
OUTNUMBER	4	_ _TN_MB_ _	_TN_ _ _MB_	_ _NT_BM_ _

OVERDRESS	4	_ _ER_RE_ _	_ER_ _ _RE_	_ _RE_ER_ _
PARALEGAL	4	_ _RA_EG_ _	_RA_ _ _EG_	_ _AR_GE_ _
PHONOLOGY	4	_ _ON_LO_ _	_ON_ _ _LO_	_ _NO_OL_ _
POLITICAL	4	_ _LI_IC_ _	_LI_ _ _IC_	_ _IL_CI_ _
PROFANITY	4	_ _OF_NI_ _	_OF_ _ _NI_	_ _FO_IN_ _
SIGNATURE	4	_ _GN_TU_ _	_GN_ _ _TU_	_ _NG_UT_ _
SPINELESS	4	_ _IN_LE_ _	_IN_ _ _LE_	_ _NI_EL_ _
TRACKSUIT	4	_ _AC_SU_ _	_AC_ _ _SU_	_ _CA_US_ _
WATERFALL	4	_ _TE_FA_ _	_TE_ _ _FA_	_ _ET_AF_ _
WHIRLWIND	4	_ _IR_WI_ _	_IR_ _ _WI_	_ _RI_IW_ _
WIKIPEDIA	4	_ _KI_ED_ _	_KI_ _ _ED_	_ _IK_DE_ _
WINEGLASS	4	_ _NE_LA_ _	_NE_ _ _LA_	_ _EN_AL_ _