Recognition of spoken prefixed words: The role of early conditional root uniqueness points

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Wurm (1997) introduced a construct called the Conditional Root Uniqueness Point (CRUP), which was defined as the uniqueness point of the free root of a prefixed word, given the prefix in question. About one in eight prefixed words with free roots is a CRUP word, which means that it has a CRUP that precedes its full-form uniqueness Point (UP) by at least one phoneme. In all other cases, the CRUP and full-form UP coincide. This study contrasts recognition performance for auditorily-presented CRUP words with performance on direct competitors of CRUP words, and also with performance on a group of control words. Lexical decision and naming latencies indicate a substantial processing advantage for CRUP words. Importantly, performance on direct competitors was no worse than performance on control words. This suggests that the competition among word candidates is a passive, bottom-up process. Implications for models of word recognition are discussed.

1. Introduction

Marslen-Wilson’s cohort theory (Marslen-Wilson, 1984, 1987, 1989, 1990; Marslen-Wilson and Welsh, 1978) introduced the concept of the uniqueness point (UP), defined as the point in the acoustic signal where a given word diverges from all other words in the language. By definition, this is the earliest possible point at which a word can be recognized, in the absence of additional information, because prior to this point, more than one word is consistent with the partial input. For example, the UP of the spoken word sarcophagus is the vowel following the /k/: prior to that point, there is still ambiguity because sarcastic and its morphological relatives are also consistent with the input.

Researchers have used the UP construct extensively since the introduction of the cohort theory, sometimes attempting to marshal support for (or discredit) the construct, and also in defining test and control conditions (e.g., Frauenfelder, Segui, and Dijkstra, 1990; Kwantes and Mewhort, 1999; Marslen-Wilson, 1993; Moss, McCormick, and Tyler, 1997; Pitt and Samuel, 1995; Radeau, Morais, Mousty, and Bertelson, 2000; Radeau,
Morais, Mousty, Saerens, and Bertelson, 1992; Radeau, Mousty, and Bertelson, 1989; Radeau and Morais, 1990; Schriefers, Zwitserlood, and Roelofs, 1991; Tyler, 1984; Tyler and Marslen-Wilson, 1986; Tyler, Marslen-Wilson, Rentoul, and Hanney, 1988; Tyler and Wessels, 1983; Vakoch and Wurm, 1997; Wurm, 2000; Wurm and Ross, 2001; Wurm and Samuel, 1997; Wurm and Vakoch, 1996, 2000; Wurm, Vakoch, Strasser, Calin-Jageman, and Ross, 2001; Zwitserlood, 1989). These studies have been conducted in several different languages (primarily Dutch, English, and French), they have used both auditory and visual stimulus presentation, and they have used a very wide range of experimental paradigms, including gating, phoneme monitoring, shadowing, lexical decision, gender classification of nouns, cross-modal and unimodal priming, mispronunciation detection, naming, and measurement of event-related potentials from the surface of the scalp (ERPs - see van Petten, Coulson, Rubin, Plante, and Parks, 1999).

Wurm (1997) distinguished between two types of prefixed words with free roots (free roots are those that can stand alone as words, like the build in rebuild, in contrast to bound roots such as the -ceive in receive). To understand the difference between these stimulus types, it is also necessary to understand the difference between two different kinds of uniqueness points. One of these is the full-form UP. The full-form UP of the spoken word discredit is the second /d/, because prior to that point, words such as discretion and discrepancy are still viable candidates. This is the UP researchers typically refer to and study. The second kind of UP, though, is called the conditional root UP, or CRUP. To locate the CRUP, one removes the prefix from a word, and searches for the UP of the root. For example, to find the CRUP of discredit, one removes the prefix dis- and locates the UP of credit. However, one does not check against the entire dictionary to do this. The only items checked are free roots that can combine with this particular prefix. In this way, one ends up with the UP of this particular root, conditional on this particular prefix.

In a post hoc analysis, Wurm (1997) found that the CRUP of a prefixed word was usually at the same phoneme as its full-form UP, but that there are many exceptions. For example, the CRUP of discredit is not the second /d/, but rather the /r/: the only other words still consistent with the initial phoneme string /dis’krE-/ are discrepant, discretion, and their morphological relatives, but because the decompositional route in this model only considers free roots, those words will not be relevant (-crepant and -creation are not free morphemes). Words like discredit were called CRUP
words by Wurm and Ross (2001), although readers should note that all prefixed words have a CRUP; the key issue is where the CRUP is located relative to the full-form UP. Approximately one out of every eight prefixed words Wurm (1997) used were CRUP words.

Not everyone agrees that it is theoretically sensible to treat bound roots and free roots differently (e.g., Bergman, Hudson, and Eling, 1988; Emmorey, 1989; Stanners, Neiser, and Painton, 1979; Taft, 1994). The decision to do so is based mainly on semantic grounds, and comes from several related findings. First, Marslen-Wilson, Tyler, Waksler, and Older (1994) concluded that bound roots are not represented in the same way as free roots because they lack reliable meanings in English. Second, speakers and writers exhibit tremendous flexibility in coining new words, often by combining existing morphemes in a new way. These new combinations of morphemes, which cause little or no difficulty for listeners and readers (Baayen, 1994; Coolen, van Jaarsveld, and Schreuder, 1991; Schreuder and Flores d'Arcais, 1989), are always highly transparent forms with free roots. Other recent work shows the importance of semantics (e.g., Libben, 1998; Schreuder and Baayen, 1995; Wurm, 1997, 2000), and supports the distinction between root types: Bound roots are almost always semantically empty except perhaps to language experts, and are not generally subject to phenomena like semantic drift (e.g., Aronoff, 1976). Wurm (2000) concluded that bound roots are either represented differently in the lexicon than free roots, or at the very least, they do not have the same degree of interconnectedness to other lexical elements as free roots. This is what one would predict, based on the fact that the semantic fields of bound roots intuitively seem impoverished. Wurm’s (2000) conclusion was based on several interactions involving root type in a lexical decision experiment with morphologically complex pseudowords. Finally, Schreuder, Burani, and Baayen (in press) have also presented evidence of differential effects for free and bound roots, in a visual lexical decision experiment looking at processing of opaque complex words in Dutch.

Wurm and Ross (2001) found that auditorily presented CRUP words were processed much faster than items they called non-CRUP words. Like CRUP words, these were prefixed words carrying free roots. However, the CRUPs in non-CRUP words did not precede the full-form UPS. CRUP words enjoyed an 88-msec advantage in a lexical decision experiment and a 107-msec advantage in a naming experiment.

It is worth noting that the perceptual system cannot commit to a CRUP word at the CRUP, because there remain other words consistent with the
input. For example, at the CRUP of the spoken word discredit (i.e., at the /l/), words such as discrepancy and its morphological relatives remain viable candidates. So any advantage conferred by having a CRUP that precedes the full-form UP would have to operate via some mechanism other than simply allowing full commitment to the CRUP word. One way in which the advantage observed by Wurm and Ross (2001) could come about is through an activation boost to the free root credit at the CRUP, a boost that would not be given to bound roots like -crepancy.

It is also possible that when the perceptual system comes upon a CRUP, other kinds of computations can begin. These might include access of a grammatical category, facilitated access of a word's meaning, or integration of the lexical hypothesis with the preceding context. Consistent with these possibilities is the later version of Marslen-Wilson's cohort model, in which the initial 150 msec of acoustic input is considered sufficient for semantic information to begin to become available. Importantly, 150 msec of acoustic input is generally not enough to uniquely identify a spoken word, so semantic information is believed to become available while multiple word candidates are still consistent with the input. Zwitserlood (1989) provided very compelling experimental results that agree with this theoretical stance. In an important series of cross-modal priming experiments in Dutch, she found that auditory presentation of the initial 130 msec of a word resulted in the semantic activation of all words consistent with the input. For example, presenting the first four phonemes of words like captain and captive led to faster recognition times for probe words related to both. Finally, van Petten et al. (1999) recently found that N400 ERPs depend on contextual appropriateness, even when measured at a point well before word recognition can take place. In this study, differences in the N400 waves appeared 200 msec before the UPs of the words. The authors concluded that "...semantic integration can begin to operate with only partial, incomplete information about word identity" (p. 394). All of these results suggest that a lot may be going on in the very early stages of word recognition, which would give the possible head start offered by an early CRUP some potential value.

It is interesting to note that some additional findings in the literature may relate to CRUPs. Schriefers et al. (1991) found that Dutch prefixed words were identified earlier than unprefixed words with identical UPs, in a set of gating experiments. For example, both the prefixed word opstaan and the root staan have the final /n/ as their UP, but identification of the prefixed words was earlier by an average of 37 msec. Schriefers et al.
(1991) termed this effect the general prefixation advantage. They replicated the effect in two subsequent experiments, but concluded that the effect could not be explained by any existing model. Taft (1988) reported a finding similar to this. It would be interesting to examine the stimulus lists used in these two studies. In addition to the possibility of a CRUP influence, there may also be issues of family size in play (de Jong, Schreuder, and Baayen, 2000; Schreuder and Baayen, 1997).

The non-CRUP words used by Wurm and Ross (2001) established one important comparison group against which to judge performance on CRUP words. The choice of that stimulus type controlled for morphological complexity, in that all words in both test conditions consisted of a prefix plus a free root. However, given the nature of lexical neighborhoods and the research question being addressed, the two groups of words in that study necessarily differed along other dimensions believed to affect lexical processing. Specifically, the non-CRUP words had significantly more auditory competitors than the CRUP words (24 vs. 7), which could have slowed their processing (e.g., Grainger, 1990; Grainger and Jacobs, 1996; see also Meunier and Segui, 1999). Although efforts were made to make these differences small, they could not be eliminated completely.

The current study takes two important additional steps. First, we compare performance on CRUP words like discredit to performance on two different kinds of comparison items. One of these is direct competitor words like discretion. The CRUP theory outlined by Wurm (1997) falls apart if processing of CRUP words is not found to be significantly faster than processing of these direct competitors. The other comparison will be to a group of control items, matched carefully to the CRUP words and direct competitors in ways not possible in the Wurm and Ross (2001) study.

The second important step taken by the current study is a preliminary exploration of the mechanism behind the CRUP advantage. Because of the sequential nature of speech, a listener is dealing at any given moment with only partial information about a word, information that is frequently ambiguous and that can be interpreted in multiple ways (McQueen, Cutler, Briscoe, and Norris, 1995). Most theorists in speech perception believe that there is some form of competition between simultaneously activated lexical candidates (e.g., Frauenfelder and Peeters, 1998; McQueen et al., 1995), but there is significant disagreement about the form this competition takes. The major question has to do with how direct or active this competition is: Is the activation level of a given word determined only by its goodness of fit with the acoustic signal, or is it also influenced directly by the activation
levels of its neighbors? The former possibility is a passive, "bottom-up" type of competition hypothesized by several models of speech perception (e.g., Marslen-Wilson, 1987, 1990; Goldinger, Luce, and Pisoni, 1989; Luce, Pisoni, and Goldinger, 1990). The latter is a more direct, lateral type of inhibition hypothesized by network models of speech perception (McClelland and Elman, 1986; McQueen, Norris, and Cutler, 1994; Norris, 1994). Without this direct type of inhibition among competitors, there is apparently no clear way for the proper word candidate to emerge in these models (McQueen et al., 1995).

2. Experiment 1: Lexical decision

2.1. Method

2.1.1. Participants

Fifty-six undergraduates from the psychology subject pool at Wayne State University participated in this experiment. All reported normal hearing and received extra credit in a psychology course for their participation.

2.1.2. Materials

As mentioned above, the existence of a CRUP word necessarily implies a direct competitor. For example, discredited is a CRUP word only because of the existence of words like discretion and discrepant, which are its direct competitors. Twenty CRUP words identified by Wurm and Ross (2001) were used as a starting point. A computer program was written to search the CELEX database (Baayen, Piepenbrock, and van Rijn, 1993; Burnage, 1990) for words that match each CRUP word up to a pre-specified location. Specifically, any word matching a CRUP word at least as far as the CRUP can be considered a direct competitor. For example, the CRUP of discredited is the /r/ sound, and words such as discretion and discrepant match to that point. Twenty stress-matched direct competitors were identified using this procedure.

An equal number of words were selected as an additional comparison group. These were selected by the same method, but words were only eligible if they diverge from a CRUP word before the CRUP. For example,
discordant matches the CRUP word discredit up to the phoneme immediately preceding the CRUP, so it was considered a potential control word. These words, then, also compete with CRUP words, but the competition ends prior to the CRUP. This set of items was pared to a total of 20 words, matched as closely as possible to the direct competitor items on several variables of interest (see Table 1 and the Appendix).

Table 1. Summary Statistics (Means) for Critical Stimuli.

<table>
<thead>
<tr>
<th></th>
<th>CRUP words</th>
<th>direct competitors</th>
<th>control words</th>
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<tbody>
<tr>
<td>Duration (msec)</td>
<td>701</td>
<td>692</td>
<td>697</td>
</tr>
<tr>
<td>Length (phonemes)</td>
<td>6</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Uniqueness Point (msec) b</td>
<td>501</td>
<td>502</td>
<td>486</td>
</tr>
<tr>
<td>Frequency (per million) a</td>
<td>2</td>
<td>14</td>
<td>12</td>
</tr>
<tr>
<td>Auditory Competitors</td>
<td>8</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>Competitors' Frequency (per million) a</td>
<td>40</td>
<td>60</td>
<td>51</td>
</tr>
</tbody>
</table>

Note. None of the differences approached significance.

Frequency values were taken from the Birmingham/Cobuild corpus (17.9 million tokens) of the CELEX database (Baayen et al., 1993; Burnage, 1990).

Auditory competitors are words that diverge from a given stimulus word at the phoneme prior to the uniqueness point. Alternatively, this can be thought of as the cohort size at the phoneme just prior to the uniqueness point.

An additional 240 words were chosen at random from the same database. One hundred and fifty of these were changed into pronounceable pseudowords via a randomly-placed change of a single phoneme (e.g., the word sharpened became the pseudoword farpened). The remainder were retained as filler items. Stimuli were digitized at a sampling rate of 20 kHz, low-pass filtered at 9.8 kHz to prevent aliasing, and stored in individual disk files.

RTs were measured from the UP of each presented stimulus, which was defined as the middle of the prototypical segment of the particular phone in question (following Radeau et al., 1989; see also Wurm and Ross, 2001). This point was located using both visual and auditory criteria, with the help of a commercial waveform editor (Cool Edit 2000). As Table 1 shows, the temporal location of the UP was quite closely matched across the three stimulus types.
There are two reasons RTs were measured from this time point. First, this is the theoretically earliest moment at which the perceptual system can commit to a single word candidate with absolute certainty about the word being processed, so it would seem to be a good theoretical choice. Second, this is the same method used by Wurm and Ross (2001) and Wurm (1997), so this allows direct comparison of performance across studies. In fact, thought, the pattern of results depends very little on whether this location is used, as opposed to word onset or offset, because the item durations and uniqueness point locations are so well matched.

2.1.3. Procedure

Participants were tested in groups of one to three in a sound-attenuating booth. They listened to the stimuli, played over headphones at a comfortable listening level, and were instructed to make a speeded lexical decision about each stimulus. Each participant pressed one button for words, using the index finger of his or her dominant hand, and a different button for pseudowords, using the index finger of his or her non-dominant hand. A different random stimulus order was used for each group of one to three participants. A practice set of 40 stimuli (20 words and 20 pseudowords) was used prior to the main experiment to familiarize participants with the procedure.

The first major goal of this paper will be accomplished by comparing performance on CRUP words to performance on the other two stimulus types. The most obvious prediction of the CRUP theory is that CRUP words will be processed faster than direct competitors; also, based on the findings of Wurm and Ross (2001), we expect CRUP words to be processed faster than control words.

The other major goal of this paper will be accomplished by comparing performance on control words to performance on direct competitors. Both kinds of words are in competition with CRUP words, but to different degrees. We wanted to know whether this would translate to different performance for the two types of stimuli. Direct competitors might have poorer performance than control words for two related reasons, both of which can be traced to the issue of how direct inter-lexical competition is. First, the portion of a direct competitor word (but not a control word) that overlaps with a CRUP word includes the CRUP, a point hypothesized to be of special importance. According to the hypothesis we have laid out previ-
ously, CRUP words will have their activation levels increased substantially at this point. Second, direct competitors are more similar phonetically to CRUP words than are control words, and more highly similar items are hypothesized to inhibit each other more strongly (e.g., McClelland and Elman, 1986). The question is, does this additional overlap, which includes the CRUP, result in measurable processing difficulty for direct competitors? If so, we should observe slower (and possibly less accurate) performance on direct competitor items such as discretion than on matched control items such as discordant. Alternatively, if competition among word candidates is the passive, bottom-up type, then the CRUP advantage would derive solely from facilitation of the CRUP word, and not through any direct inhibitory mechanism. This predicts that performance on direct competitors will be indistinguishable from performance on control words.

2.2. Results and discussion

The error rate analyses did not show any significant differences, so we will present only the RT analyses. RTs for trials on which the participant incorrectly classified a critical stimulus as a pseudoword were not included in the analyses (5.0% of the critical trials). RTs were discarded if they were more than two standard deviations above the mean for a given participant in a given condition or for a particular item (3.8% of the data).

Figure 1 shows the mean lexical decision times for each type of stimulus. The effect of stimulus type was significant by both subjects and items (F1[2,110] = 8.68, p < .01; F2[2,57] = 3.17, p < .05). Planned comparisons showed that CRUP words had significantly shorter lexical decision times than did direct competitors (F1[1,55] = 8.86, p < .01; F2[1,38] = 4.29, p < .05) or control words (F1[1,55] = 9.91, p < .01; F2[1,38] = 4.19, p < .05). These outcomes provide additional support for the psychological validity of the CRUP construct, and also extend the results of Wurm and Ross (2001) to better-controlled comparison groups.
As for the question of how the CRUP advantage works, we turn to the comparison of direct competitor RTs and control RTs. The small difference was not significant (both F-ratios < 1.0). Together with the substantial CRUP advantage, this equality of RTs suggests that the competition among word candidates is a bottom-up, passive kind that depends on degree of fit with the acoustic signal, rather than a direct competition in which activation levels are directly influenced by neighboring words.

If the mechanism behind the observed CRUP advantage operates as we have hypothesized, then in principle, the magnitude of this advantage should be related to the distance between the CRUP and the full-form UP. That is, we have conjectured that CRUP words get a head start on processing at the CRUP, because of a boost in activation provided to the CRUP-aided root. Logically, we should expect that the earlier this head start begins, the larger the CRUP advantage should be. With this in mind, we computed correlations to see if there was in fact any relationship. One of the variables used in the correlations was the CRUP-to-UP distance, in msec, for each of the 20 CRUP words. The other variable was the CRUP advantage, calculated as the mean RT for a direct competitor minus the
mean RT for its matched CRUP word (analogously, we subtracted mean RT for each CRUP word from the mean RT for its matched control word). Both of these correlations were strong and significant: \( r = .68 \) for the CRUP advantage over direct competitors, and \( r = .61 \) for the CRUP advantage over control words (both \( ps < .01 \)). This lends an additional measure of support to our interpretation of the CRUP advantage and to our hypothesis about its operation.

In order to guard against overinterpreting these findings, however, it is prudent to replicate this pattern of results with an additional experimental task. The lexical decision paradigm has been criticized for various reasons (e.g., Balota, 1990; Balota and Chumbley, 1984, 1985; Balota and Lorch, 1986; Chumbley and Balota, 1984; Lorch, Balota, and Stamm, 1986). While no experimental task is perfect, the naming task is widely believed to be less susceptible to post-perceptual biases than the lexical decision task, and to be free of decision-level effects (Bates and Liu, 1996; Forster and Chambers, 1973; Seidenberg, Waters, Sanders, and Langer, 1984).

3. Experiment 2: Naming

The goal of this experiment was to replicate the results of Experiment 1 using a different experimental paradigm, the naming task. On each trial, a participant heard a word presented over headphones, and repeated the word into a microphone as quickly as possible.

If the results of Experiment 1 reflect something real about lexical access processes, then we would expect to see very similar results with the naming paradigm. On the other hand, if the results of Experiment 1 are due to problems of post-access contamination stemming from the lexical decision task, the effects should disappear.

3.1. Method

3.1.1. Participants

Forty participants from the same subject pool were used in this experiment. All reported normal hearing and received extra credit in a psychology course for their participation. None had participated in Experiment 1.
3.1.2. Materials

The materials presented to participants were the same as those used in Experiment 1, except that the pseudowords were not included. Because of the way in which stimuli were selected, the initial phonemes of the stimuli in the three groups were matched perfectly. This variable can have a large effect on naming times (e.g., Bates, Devescovi, Pizzamiglio, and D'Amico, 1995) because voice keys are likely to be triggered sooner by words with abrupt onsets. In fact, all phonemes corresponding to the prefix for the trio were matched, and we attempted to match phonemes beyond the prefix as well, where possible.

3.1.3. Procedure

Participants were tested individually in a sound-attenuating booth. They listened to the stimuli, played over headphones at a comfortable listening level, and were instructed to repeat back each word they heard as quickly and accurately as possible. A microphone was positioned approximately 10 cm in front of each participant. A different random stimulus order was used for each participant. As in Experiment 1, response times were measured from the UP of each presented stimulus. A practice set of 20 words was used prior to the main experiment to familiarize participants with the procedure.

3.2. Results and discussion

As in Experiment 1, the error analyses showed no significant differences. We again therefore present only the RT analyses. Naming times for trials on which the participant pronounced the wrong word were not included (2.7% of the trials). RTs were also excluded from the analyses if they were due to a noise other than initiation of the verbal response, like coughing or clearing of the throat (< 1% of the data). Finally, RTs were discarded if they were more than two standard deviations above the mean for a given participant in a given condition or for a particular item (< 1% of the data), as in Experiment 1.
The naming experiment replicates the findings of the lexical decision experiment almost perfectly. Figure 2 shows mean naming latencies for each type of stimulus. As in Experiment 1, there was a large and significant effect of stimulus type (F1[2,78] = 5.03, p < .01; F2[2,57] = 3.63, p < .05). Planned comparisons showed CRUP words were named significantly faster than direct competitors (F1[1,39] = 4.47, p < .05; F2[1,38] = 4.24, p < .05) and control words (F1[1,39] = 6.10, p < .05; F2[1,38] = 5.09, p < .05). The magnitude of the advantage found here averages 87 msec, and is on the same order as that that reported by Wurm and Ross (2001).

The difference between direct competitors and control words was not significant, in agreement with the results of Experiment 1 (both F-ratios < 1.0). This provides additional support to the conclusion we reached earlier, that competition among word candidates is more accurately characterized as a passive, bottom-up process.

We once again checked to see if the magnitude of the CRUP advantage was related to the CRUP-to-UP distance, by computing the correlations between these two variables. As in the lexical decision experiment, both correlations were strong and significant: r = .80 for the CRUP advantage
over direct competitors, and \( r = .68 \) for the CRUP advantage over control words (both \( ps < .01 \)). This once again lends support to our hypothesis about how the CRUP advantage is being realized.

4. General discussion

In the Introduction we noted that the uniqueness point has spawned a tremendous amount of research since its introduction. Some of that research has questioned the usefulness or validity of the concept. Recently, Radeau et al. (2000) concluded that UP effects in speech perception are strategic, and that the UP is a concept that has no relevance to normal spoken word recognition. It is possible that the authors were not looking at the concept in quite the right way, and that their conclusion may have been premature.

The current study replicates the basic finding of a CRUP advantage with a different set of experimental controls, and extends it in two important ways. First, the theory was tested more directly; CRUP words were compared to their direct competitor items, as defined by the original formulation of the construct (Wurm, 1997). Second, an additional control group was included, comprised of well-matched items that were neither CRUP words nor direct competitors of CRUP words.

It may seem that the CRUP advantage in the present study is confounded with boundedness. Specifically, the CRUP words carried free roots, while the other stimuli were a mixture of items carrying bound roots and monomorphic items. However, there are a number of reasons why this is not a major concern. First, the Wurm and Ross (2001) study showed that the CRUP advantage exists even when boundedness is controlled for. In that study, all words in both test conditions consisted of a prefix plus a free root. Second, ignoring for the moment the fact that some of the items were truly prefixed and some were not, we can compare the frequencies of occurrence of the word-final strings. This comparison shows that the frequencies in fact are similar: the mean lemma frequency for the free roots in CRUP words was 142 per million, while the mean frequencies for the word-final strings in the other stimulus groups were 115 per million (for direct competitors) and 165 per million (for control words). It would be hard to argue that this factor is influencing the outcome of the current study, because not only are the frequencies similar, but one stimulus group is higher and one lower than CRUP words. Finally, the correlational analy-
ses presented in the current study also demonstrate that CRUPs are involved in the recognition process.

The large advantage found for CRUP words in the current study, as measured against two different kinds of comparison groups, does indeed suggest that the construct is psychologically real. The probabilistic information associated with CRUPs appears to be tracked and used to considerable advantage. The RT advantages for CRUP items over direct competitors and control words suggest that encountering a CRUP before the full-form UP makes a difference perceptually. Given the relative scarcity of CRUP words (only about one-eighth of all prefixed words with free roots), this is truly impressive.

As we discussed previously, even though the perceptual system cannot commit fully to a word candidate at the CRUP, it is theoretically possible that certain kinds of computations get a head start at this point. The correlational analyses we conducted lend strong support to this idea. They revealed a strong linear relationship between the size of this theoretical head start and the magnitude of the CRUP advantage eventually realized for a given word. This finding was significant in both experiments, and for the CRUP advantage over both other kinds of stimuli used in the study.

No existing model of speech perception has made mention of the CRUPs construct, but dual-route models seem particularly well-suited to accommodate findings such as these. Specifically, in dual-route models, at least some complex words are explicitly represented in terms of their constituent morphemes. Which words are represented in this way differs from model to model, but it seems straightforward in an arrangement with explicit morphological representation to modify which elements are linked to which other elements.

Two examples of dual-route models are the Augmented Addressed Morphology (AAM) model (Caramazza, Laudanna, and Romani, 1988; Laudanna and Burani, 1995; Laudanna, Burani, and Cermel, 1994; Laudanna, Cermel, and Caramazza, 1997) and Morphological Race Model (MRM: Frauenfelder and Schreuder, 1992; Schreuder and Baayen, 1995; see also Baayen, Dijkstra, and Schreuder, 1997). In each of these models there are competing routes to word recognition. In the AAM model the whole-word route wins the competition for known words, except in some very special cases that do not apply in the current study (e.g., for words with extremely low full-form frequency and extremely high individual morpheme frequencies). The MRM appears to be the more promising of the two. It is similar to the AAM model in many ways, except that it is not
a given that the whole-word route will win for known words; other morphological factors (e.g., semantic transparency, productivity) also come into play. If modified to keep track of specific root lists in the way we have described, so that only a subset of the lexicon is considered once a prefix has been identified, the MRM might be able to accommodate these results.

Taft’s (1994) interactive-activation proposal, which is most accurately characterized as a “full decomposition” model, offers another attractive starting position from which to explain these data, although it, too, would need modification. That model has a level of representation for bound morphemes (i.e., prefixes and bound roots), and one where all free-standing words (including polymorphemic words) are represented. A key part of the model, for our present purposes, is that elements that combine to make larger words are interconnected, whether free or bound. Wurm (2000) proposed that this framework could explain his lexical decision data for morphologically complex spoken pseudowords, but in the present case, the framework would appear to need modification. Specifically, we would expect the observed outcome if bound roots were not lexically represented. There is currently a great deal of debate in the literature on this point (see Marslen-Wilson et al. [1994] and Taft [1994] for opposing views). A functionally equivalent possibility would be to modify how the represented elements are linked to each other. In Taft’s (1994) model, all elements that combine to make words are interconnected; the current results, along with those of Wurm and Ross (2001), suggest that prefixes need to be linked to the free roots that they can combine with, but not to bound roots.

Future research should aim to replicate and extend the findings of Schriefers et al. (1991) and Taft (1988) as these may relate to CRUPPs. The ERP paradigm might be used profitably in extending research efforts in this area, as well, as demonstrated by van Petten et al.‘s (1999) finding that semantic information builds considerably before a word’s UP. If future research provides additional support for the findings of the current study, existing models will need to be modified in significant ways.

A critical additional question addressed in the current study had to do with the mechanism of competition, which seems to be a requirement for spoken language (see Drews and Zwitserlood, [1995], and Forster and Shen [1996] for opposing views on competition in reading). We were interested in determining whether direct competitors of CRUP words suffer a measurable penalty, as compared to similar word that do not happen to have this special relationship. Control words overlapped with CRUP words by 1.5 phonemes less, on average, than direct competitors did. Crucially,
for control words, this overlap did not include the CRUP, which has been shown in this and a previous study to be a point that has significant perceptual consequences.

Our failure to find any difference between these stimulus types in two experiments using very different experimental paradigms suggests that CRUP words do not exert any direct influence on the activation levels of competing words, and thus argues for a more passive kind of competition that depends only on bottom-up fit with the acoustic signal. Although not explicitly addressed, it appears that Taft's model includes direct active competition. Both the MRM and AAM model, on the other hand, appear to use the passive form of competition, although as we noted above, the MRM is probably to be preferred on other grounds.

It is useful at this point to work through an example that illustrates the processes we have been describing. Let us contrast the processing of a CRUP word with processing of a direct competitor (the contrast between a CRUP word and a control word would follow the same line of reasoning). Imagine that the acoustic signal corresponding to the letters discrete has been heard. At that moment the whole-word route would be in the process of mapping the signal onto both discredit and discrepant (we can assume equally for purposes of illustration). The decompositional route would have already mapped the beginning portion of the signal onto the prefix representation (i.e., dis-), and would be attempting to map the following portion of the signal. As outlined by the CRUP model, this mapping procedure would only include free elements that can combine with dis-. The only one that fits this bill is credit, so its activation level would be increased. This activation of credit would also increase the activation level of the whole-word representation for discredit, because the two are hypothesized to be linked.

A selective morphemic process such as that hypothesized, where free roots are linked to specific prefixes, could have formed as a result of the way language is used. Listeners and readers have very little trouble handling brand new words, coined on the fly as they are needed by speakers and writers (Baayen, 1994; Coolen et al., 1991; Henderson, 1985; Libben, Derwing, and de Almeida, 1999; Schreuder and Flores d'Arcais, 1989). Technically pseudowords because they have no histories and no established meanings, these new words are very often morphologically complex. However, they never carry bound roots. The reason for this brings us back to the issue of semantic transparency, which was one of the requirement considered in identifying potential CRUP words (Wurm, 2000; Wurm an
Ross, 2001). Aronoff (1976) noted that new word forms are quite high on semantic transparency, while older ones may not be because of semantic drift. In addition, as asserted previously, only free roots can meet the requirement of high semantic transparency (e.g., Schreuder and Baayen, 1994). Bound roots therefore lack the capacity to be a part of novel, meaningful combinations. These facts about language use could lead to the development of a decompositional system that affords special status to free roots in transparent full-forms.

Evidence is accumulating that CRUP words are easier to process than several other kinds of words. Wurm and Ross (2001) demonstrated that CRUP words show much faster lexical decision and naming times than other prefixed words with free roots. The current study demonstrates that CRUP words enjoy a similar advantage over their direct competitors (i.e., those words whose existence makes a word a CRUP word), and over a matched group of control words that do not compete in this special way. One might wonder what is gained by investing the cognitive resources necessary to track the kind of information that defines CRUPs, because this information results in a processing benefit for only about 10-15% of the words in question. This study suggests that the gain in recognition speed is significant enough - on the order of 80-100 msec for words with early CRUPs - to warrant such an investment.

Appendix

Critical stimuli used in the experiments. Following each word is the item duration in msec (stimuli were presented auditorily), lemma frequency per million occurrences, root frequency (string frequency for Direct Competitors and Control Words) per million occurrences, uniqueness point in msec, conditional root uniqueness point in msec, mean lexical decision time in msec, and mean naming time in msec. We did not compute some string frequency values for extremely high frequency word-final strings, such as “-ing” and “-s.” These are denoted by hyphens in the table. Also, only CRUP words have a conditional root uniqueness point, so this space is marked by hyphens in the other stimulus groups.

**CRUP words**

<table>
<thead>
<tr>
<th>Word</th>
<th>Duration</th>
<th>Frequency</th>
<th>Root Frequency</th>
<th>Uniqueness</th>
<th>Decision Time</th>
<th>Naming Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>ablaze</td>
<td>781</td>
<td>4.2</td>
<td>1.4</td>
<td>4.2</td>
<td>251</td>
<td>294</td>
</tr>
<tr>
<td>afloat</td>
<td>564</td>
<td>10.2</td>
<td>1.1</td>
<td>10.2</td>
<td>305</td>
<td>251</td>
</tr>
<tr>
<td>anew</td>
<td>710</td>
<td>1070.3</td>
<td>1.8</td>
<td>710</td>
<td>135</td>
<td>311</td>
</tr>
<tr>
<td>debrief</td>
<td>674</td>
<td>570</td>
<td>0.2</td>
<td>4.7</td>
<td>261</td>
<td>350</td>
</tr>
</tbody>
</table>


decode, 620, 2.0, 4.5, 523, 327, 471, 366
discredit, 643, 0.8, 6.3, 372, 290, 687, 604
distrust, 725, 3.3, 47.9, 488, 191, 522, 438
enact, 539, 5.0, 123.6, 383, 204, 728, 563
inflame, 688, 2.2, 25.6, 593, 423, 374, 234
midstream, 778, 0.1, 48.2, 406, 338, 586, 594
preset, 608, 0.0, 314.5, 571, 247, 583, 412
refresh, 660, 5.1, 71.6, 372, 294, 831, 629
regroup, 634, 1.8, 5.2, 400, 301, 681, 555
rejoin, 711, 3.8, 144.9, 411, 375, 345, 106
relive, 756, 2.9, 523.5, 661, 453, 318, 271
substandard, 933, 0.4, 33.4, 667, 512, 321, 291
subzero, 764, 0.0, 16.9, 384, 311, 709, 54
surcharge, 740, 0.0, 45.1, 414, 314, 938, 574
surnament, 665, 3.0, 40.8, 385, 224, 707, 605
surreal, 836, 0.8, 299.1, 702, 328, 337, 309

Direct competitors
ablative, 595, 0.0, 5.8, 318, —, 966, 698
afflict, 639, 5.6, 76.2, 327, —, 737, 693
annuity, 696, 1.3, 17.6, 333, —, 884, 697
debris, 553, 8.3, 9.3, 553, —, 468, 389
decor, 591, 3.0, 5.8, 591, —, 452, 371
discrepant, 746, 0.1, 3.4, 403, —, 882, 663
distress, 744, 9.5, 314.4, 405, —, 627, 623
enamel, 629, 6.5, 34.5, 536, —, 652, 487
inflated, 652, 3.3, 57.1, 582, —, 468, 458
misd, 584, 13.2, —, 540, —, 820, 475
precede, 773, 12.5, 41.8, 496, —, 774, 565
refrain, 703, 7.5, 7.5, 612, —, 483, 407
regress, 702, 1.3, 213.5, 576, —, 554, 424
rejoice, 776, 5.9, 7.9, 655, —, 445, 313
religion, 736, 57.5, 125.0, 380, —, 683, 659
substantial, 956, 33.5, 46.2, 829, —, 663, 511
subsumes, 589, 0.0, —, 588, —, 709, 353
searching, 697, 48.5, —, 446, —, 572, 530
surmise, 691, 3.0, 35.8, 408, —, 811, 587
surround, 797, 49.4, 953.1, 463, —, 629, 568
Control words
abrade, 589, 0.3, 3.7, 589, —, 969, 616
affront, 619, 2.1, 345.0, 354, —, 912, 531
amenity, 684, 7.9, 10.7, 432, —, 726, 664
debase, 564, 2.4, 106.8, 472, —, 670, 451
decay, 592, 17.9, 19.6, 410, —, 555, 540
discordant, 754, 1.1, 341.2, 443, —, 800, 587
disgust, 737, 16.9, 38.0, 737, —, 643, 616
enigma, 626, 2.8, 10.9, 519, —, 738, 686
inflict, 663, 0.0, 76.1, 383, —, 601, 664
midget, 583, 1.9, 54.0, 369, —, 645, 538
preside, 757, 10.6, 15.2, 422, —, 673, 565
reflect, 735, 78.0, 118.5, 553, —, 425, 370
recline, 724, 3.9, 95.4, 437, —, 548, 563
restrain, 780, 13.0, 109.0, 497, —, 612, 445
relation, 758, 39.2, 700.9, 412, —, 585, 552
subtraction, 978, 1.3, 314.4, 431, —, 749, 661
suds, 587, 1.2, —, 524, —, 697, 393
surgeon, 714, 11.4, 11.6, 600, —, 516, 438
survey, 696, 14.1, 88.0, 696, —, 396, 235
surpass, 794, 3.1, 673.2, 446, —, 568, 498

Notes
1. Suffixation complicates the definition of a uniqueness point. If we are interested in computing the UP of the spoken word brief, for instance, it makes a difference whether we consider forms such as briefly to be potential competitors. The usual approach, and the one adopted in this study, is not to consider morphologically related suffixed forms to be competitors (Marslen-Wilson, 1984; Tyler, Marslen-Wilson, Rentoul, and Hanney, 1988). Wurm and Ross (2001) found that the decision makes little practical significance unless the words of interest are short. For the words used in the current study, suffixed continuations were fairly rare and were evenly distributed among the different stimulus groups.
2. Analogously, we can define the CRUP-to-UP distance in terms of phonemes, rather than in msec. In this case simple t-tests can be conducted to see if the CRUP advantage is larger for stimuli in which the CRUP-to-UP distance is two phonemes, as opposed to those in which this distance is only one phoneme. These additional analyses lead us to the same conclusion: the CRUP
advantage was significantly larger when the CRUP-to-UP distance was two phonemes (both ps < .01). We would like to thank Jen Hay for clarifying our thinking about this issue.

3. As in Experiment 1, if we define the CRUP-to-UP distance in phonemes rather than in msec, the CRUP advantage is significantly larger when the CRUP-to-UP distance is two phonemes (both ps < .01).

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