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Conditional Root Uniqueness Points and Cohort Entropy Effects in Spoken Dutch

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Abstract

Wurm (1997) introduced the Conditional Root Uniqueness Point (CRUP), defined as the UP of a prefixed word given the prefix in question. English prefixed words with early CRUPs have a large recognition time advantage (Wurm & Aycock, 2003; Wurm & Ross, 2001), and the current study attempted to replicate this advantage in spoken Dutch. The second purpose of the study was to examine the possibility of gaining further insight into the time-course of lexical disambiguation by means of several entropy measures and to establish whether the CRUP construct is independent of these entropies as well as of morphological family size. CRUP words and well-matched Control words were presented auditorily to native speakers of Dutch, who performed speeded lexical decision. Three entropy measures and morphological family size emerged as significant predictors of reaction times. CRUP words were not recognized significantly faster than Control words, but stimulus group (i.e., CRUP vs. Control) did interact with one of the entropy measures and with morphological family size. In addition, the temporal distance from the CRUP to the UP was related to overall RTs, especially for CRUP words with higher frequencies. Considered jointly, these results suggest a different time course of lexical disambiguation for CRUP words as compared to their controls.

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More than 25 years ago Marslen-Wilson and Welsh (1978) introduced the *uniqueness point* (UP), the point at which a spoken word diverges from all other words in a language. For example, the UP of the word *sarcophagus* ([sɑr'kɑfəgəs] in American English) is the second [ɑ]: prior to that point, other words remain consistent with the acoustic input (e.g., *sarcastic*). A very large number of studies have used the UP in establishing test conditions, or have examined the UP itself as a construct of interest (see Wurm & Ross, 2001).

To explain the results of gating and lexical decision data for prefixed English words, Wurm (1997) proposed that words were simultaneously analyzed as full-forms and as individual morphemes. What differentiated this from the many other dual-route proposals in the literature was a unique constraint imposed on the morphemic recognition route. Specifically, after a potential prefix is stripped off, the morphemic route attempts to match the remaining portion of the acoustic signal not to the entire lexicon, but only to a small subset of it. In particular, only free roots (e.g., the *build* in *rebuild*) are considered, not bound roots (e.g., the *-ceive* in *receive*). Furthermore, the only free roots considered are those that have in the past combined with this particular prefix. The UP that is relevant to this route of the model was called the *conditional root UP,* or CRUP. It is the UP of a root morpheme, given the prefix that has been processed.

This selective morphemic process that pays special attention to prefix + free root combinations could form as a result of the way language is used. Speakers and writers coin new words on the fly as needed, and listeners and readers have very little trouble in handling them (Baayen, 1994; Coolen, van Jaarsveld, & Schreuder, 1991; Henderson, 1985; Schreuder & Flores d'Arcais, 1989). These newly-coined words are often morphologically complex, but they never carry bound roots. It is possible that the perceptual system would pick up on this pattern, which could lead to a system that affords special status to specific combinations of prefixes and free roots.

The CRUP of a prefixed word can either be the same phoneme as its full-form UP or it can precede the full-form UP. An example can help make this clear. The full-form UP of the spoken word *discredit* is the second [d]; listeners must hear this much to ensure that the word being uttered is not *discrepant, discretion, discriminate,* or a word related to these. The CRUP of *discredit,* though, is the [r], because it turns out that there are no other words with free roots that begin with [dɪs'kr] besides *discredit.* Following Wurm (1997; Wurm & Aycock, 2003; Wurm & Ross, 2001) we will refer to words in which the CRUP and the UP differ as *CRUP words;* words in which the two UPs coincide will be considered Control words.

Wurm (1997) studied 72 prefixed words, which were selected before the CRUP construct was formulated; nine of them turned out to be CRUP words. Post hoc analyses showed that these CRUP words were recognized an average of 47 msec faster than control words in a gating experiment and 46 msec faster in a lexical decision experiment. Wurm and Ross (2001) contrasted twenty CRUP words and twenty morphological control words. These control words had coinciding CRUPs and UPs and were chosen to be matched to the CRUP words on as many other variables as possible. Wurm and Ross found a large performance advantage for CRUP words (46 msec in a lexical decision experiment and 67 msec in a naming experiment).

Wurm and Aycock (2003) replicated the CRUP advantage against two other kinds of control stimuli, but it is as yet unknown whether the CRUP construct has any relation to auditory processing in a language other than English. This is important to establish, because if previously reported effects are found to apply in a second language, the findings would speak much more generally to the issue of how various kinds of complex information are used by the human perceptual system. In the current study, we focused on Dutch. Dutch has been studied extensively by linguists and psycholinguists, so a large array of language statistics is available. Furthermore, Dutch has a lower overall proportion of CRUP words than English so it is not obvious that there will be an overall CRUP advantage. Only four percent of the Dutch words starting with the prefixes *be-, ge-, ont-,* or *ver-* are CRUP words; and the overall percentage is probably even lower among the words prefixed with other Dutch prefixes, because these words have fewer competitors with pseudoprefixes or bound stems. Some other differences between Dutch and English will be described below, as they are relevant to the pattern of results.

A second major purpose of the current study is to gain a better understanding of the underpinnings of the processing differences between CRUP words and control words. In the current study we examine the effects of some variables not included in the Wurm and Ross (2001) study. One of these variables is the morphological family size, usually defined as the number of compounds and derived words that a given simplex word (i.e., stem) appears in as a constituent. Research has shown that this variable has a facilitative effect on visual and auditory lexical decision times of monomorphemic words (Schreuder & Baayen, 1997; Baayen, Tweedie & Schreuder, 2002) and visual lexical decision times of complex words (Bertram, Baayen & Schreuder, 2000; de Jong, Schreuder, & Baayen, 2000), but to date there has not been a demonstration of a family size effect in the auditory processing literature for complex words, nor has the possibility of a confound between family size and CRUP status been studied.

A second set of variables that we consider in this study addresses the question whether the CRUP distinction might be reduced to differences in the difficulty of auditory lexical disambiguation of prefixed words at different moments in time. In order to measure changes in this difficulty as the acoustic signal unfolds over time, we made use of Shannon's entropy, calculated over the probability distribution of the lexical competitor sets at three positions in the root (cf. Kemps, Wurm, Ernestus, Schreuder, & Baayen, in press; for other recent applications of entropy in psycholinguistics, see Kostić, Marković, & Baucal, 2003 and Moscoso del Prado Martín, Kostić, & Baayen, in press.) If these measures turn out to be significant covariates, they will not only help us to better understand the time course of lexical disambiguation, they will also allow us to establish whether CRUP words and Control words have similar or dissimilar entropy profiles, or whether similar entropy profiles have different processing consequences for CRUP words and Control words.

Selection of Critical Stimuli

In order to compute UPs and CRUPs, the appropriate competitor set needs to be clearly defined. We began by selecting four productive Dutch prefixes (*be-*, *ge-*, *ont-*, and *ver-*). For each one, a computer program searched through the CELEX lexical database (Baayen, Piepenbrock, & Gulikers, 1995), compiling a list of the items marked as consisting of the prefix plus a monomorphemic root. The point at which each root diverges from the other roots *in this prefix-specific list* was determined; this is the CRUP for each word. This excludes pseudoprefixed words and words with bound roots, because they are explicitly to be excluded according to our definition of the CRUP (Wurm, 1997; Wurm & Ross, 2001). In order to find the standard UP for each prefixed word, a program simply determined the point at which each word diverges from all of the other words in CELEX. If the CRUP and the UP were not the same phoneme, the word is a CRUP word and we selected it for use pending our ability to match it with a control word (see below). In locating CRUPs and UPs, suffixed forms related to the word in question were excluded from consideration, following Marslen-Wilson (1984), Tyler, Marslen-Wilson, Rentoul, and Hanney (1988), and our earlier studies (Wurm, 1997; Wurm & Aycock, 2003; Wurm & Ross, 2001). Thus, for example, the UP of the spoken English word *distaste* is the [eɪ], in spite of the existence of the related word *distasteful.* We will return to this point below.

Twenty CRUP words were identified using this procedure. An additional 20 prefixed words were chosen to be matched as closely as possible on phonological properties. Words in the two conditions had exactly equal numbers of phonemes, and had UPs at precisely the same phoneme positions within the words. When measured in the sound files themselves, the mean UP was 581 msec for CRUP words and 587 for Control words, a difference that did not approach significance ($p = .85$). In addition, we attempted to match items as closely as possible on a number of variables known to affect lexical processing. These are described in the next section. The 40 critical stimuli are shown in the Appendix, and an example of each type of stimulus is shown in Figure 1.

Calculation of Other Independent Variables

Whole-word surface frequencies and root frequencies were gathered from CELEX (Baayen et al., 1995). Family sizes were computed as the number of compounds and derived words in CELEX in which a given stimulus word's root appears as a constituent (de Jong et al., 2000; Schreuder & Baayen, 1997). Item durations in msec were measured directly from the individual sound files.

As stated above, one of the purposes of this study was to examine whether the difference between CRUP words and Control words might be confounded with or reducible to differences in the difficulty of the disambiguation process leading to lexical identification. If CRUP words have fewer lexical competitors, or lexical competitors with specific probability distributions, the advantage observed in previous studies for CRUP words might fall out naturally as a consequence of their cohort dynamics. We opted for Shannon’s entropy H as a measure for probing lexical competition:

$$H = \sum_{i=1}^{C} p_i \log_2\left(\frac{1}{p_i}\right),$$

where *C* equals the number of words in the current cohort. *p* ranges over all the words in the cohort, and represents a given word's frequency divided by the summed token frequencies from CELEX (Baayen et al., 1995) of all the cohort members. In general, the entropy of a probability distribution is a measure of its average amount of information, and hence its informational complexity. For the present purposes, the entropy can be thought of as a token-weighted type count. A higher entropy value indicates that a word has more competitors, or competitors that are more similar in frequency (leading to greater competition), or both. In order to capture the dynamics of lexical competition, we calculated the entropy for different points in the root, in an attempt to assess how information complexity at various points (as we proceed through the word, with a continuously decreasing cohort) is reflected in the response times.

Entropy Measures

We will focus on three entropy measures, which we call *pre-CRUP entropy, CRUP entropy,* and *late entropy*. Each was calculated over all words in CELEX that matched the target word from onset up to one of three positions: 1) two phonemes into the root morpheme (pre-CRUP entropy); 2) the CRUP location, or matched location in Control words (CRUP entropy); and 3) the final segment of the word (late entropy, a measure first explored in Kemps et al., in press). There are substantial entropy differences associated with the prefixes themselves, but we controlled for these by our inclusion of the same prefixes, the same number of times, in the sets of CRUP and Control words (prefix will also be included as a factor in the analyses). Note that these entropy measures are calculated blindly across the CELEX database, and thus include items such as morphologically-related continuation forms that were deliberately excluded from the UP and CRUP computations described above.

Table 1 shows mean values for the two stimulus types on these variables. Note that the values of the three entropies decrease the further into the root we measure, from 2.24 and 2.25 for the pre-CRUP entropy to 1.45 and 1.67 for the CRUP entropy to 0.80 and 0.85 for the late entropy. For none of the measures in Table 1 did any group difference approach significance (smallest p = .28). This means that any differences in processing between CRUP words and Control words cannot be due to entropy differences that exist among the stimuli, because there are no such differences. We also ran a logistic regression analysis to determine whether membership in the group of CRUP words vs. Control words could be predicted by any of the variables shown in Table 1. No variable was retained as a predictor of group membership (smallest p = .31), so it appears that the information carried by the listed variables, plus any information carried by status as a CRUP word, are complementary. Table 2 shows the regressor intercorrelations. Word frequency and CRUP entropy are significantly correlated (r = -.33, p < .05), and likewise CRUP entropy and late entropy (r =.49, p < .01). Finally, root frequency and family size are correlated (r =.60, p <.001). None of the other correlations reached significance.

Auditory Lexical Decision Experiment

Method

Participants. Participants were 40 members of the subject pool at the Max Planck Institute for Psycholinguistics. All were native speakers of Dutch with normal hearing. Each received five euros for his or her participation.

Materials. The 40 critical stimuli, described in the previous section, are listed in the Appendix. An additional 119 words were included as part of a separate study. An equal number of pseudowords were constructed by beginning with existing words with the same morphological structures as the experimental items, and changing a single sound equally often in the beginning, the middle, and the end of the word.

Each stimulus was read by a native speaker of Dutch who was unfamiliar with the purpose and hypotheses of the study. Stimuli were digitized at a sampling rate of 16 kHz, low-pass filtered at 7.8 kHz, and stored in individual computer files.

Procedure. Participants were tested individually in a quiet room. The 318 stimuli were presented in a different random order for each participant. The digitized speech files were played for the participants over headphones at a comfortable listening level. Participants were directed to make a speeded lexical decision about each item. Each participant made responses on a button box, pressing one button for words and another for pseudowords. The "Word" response button was always pressed with the participant's preferred hand. Reaction times (RTs) were measured from the uniqueness point of each word. This allowed direct comparison to the related studies conducted in English (Wurm, 1997; Wurm & Aycock, 2003; Wurm & Ross, 2001), but there are empirical and theoretical reasons for doing this as well. First, the UP is the earliest moment at which a participant can be sure of what he or she is hearing. Second, Tyler, Moss, Galpin, and Voice (2002) found that a word's semantic information is already fully activated by the identification point, a recognition measure from the gating paradigm that is strongly correlated with the UP. Finally, Gaskell and Marslen-Wilson (1997) demonstrated with simulations that semantic ambiguity is reduced to zero at the UP of a word.

Before the main experiment, participants heard a practice list of similar composition and performed lexical decisions. The practice items were not used in the main experiment.

Results

Two participants were excluded from the analyses for inaccurate responding (> 50% errors). Three items (two Control words and one CRUP word) were excluded from the analyses. One was included in the experiment because of a transcription error, and two were categorized as pseudowords by a more than half of the participants. Finally, we excluded from the analysis extremely fast RTs (less than 150 msec after the UP; < 1% of the data) and extremely slow RTs (those longer than 2000 msec post-onset; 3.0% of the data).

Table 3 shows the overall mean RTs and error rates for the two types of stimuli. CRUP words had shorter RTs and fewer errors, but neither difference emerged as significant in a stepwise multilevel multiple regression analysis (see, e.g., Pinheiro & Bates, 2000; Baayen et al., 2002; Baayen, 2004) with participant as main grouping factor. In addition to stimulus type, we entered the covariates listed in Table 1 into the model, together with the position of a stimulus in the (randomized) presentation lists, in an effort to minimize variance attributable to practice or fatigue effects. In our analysis, we did not impose linearity *a priori,* but explored potential non-linearities (cf Baayen, in press; Harrell, 2001) by allowing quadratic terms into the model. The frequency and family size variables were transformed logarithmically in order to remove the skewness in their distributions and to minimize the effect of atypical outliers.

Table 4 lists the significant effects that were retained in the final statistical model. Position was significant, with a negative coefficient, indicating that participants became faster as the experiment progressed. There was also a significant effect of prefix, which means that words beginning with different prefixes were recognized more or less quickly than the reference prefix (*be-* in this case, as our software ordered the prefixes alphabetically for contrast coding). Word frequency had the expected facilitative relationship with RTs.

Pre-CRUP entropy had a nonlinear effect, as witnessed by significant linear and quadratic components. Figure 2 shows the combined result of these components. We made this plot by multiplying the linear and quadratic pre-CRUP entropy regression coefficients by values spanning the range of pre-CRUP entropy in our stimulus set, and by setting all other covariates to zero, stimulus type to CRUP, and prefix to *be-* (other figures were made in the same fashion). As can be seen in the figure, low pre-CRUP entropy is associated with relatively slow RTs. Items with somewhat higher pre-CRUP entropy enjoy faster RTs, but this relationship does not hold for the items that are highest on pre-CRUP entropy. At a certain point, higher pre-CRUP entropy is associated with slower RTs. This may indicate a genuine inhibitory effect for the highest pre-CRUP entropies, or alternatively, we may be observing that the effect of pre-CRUP entropy levels off for large values (and that the inhibition for higher values is an artifact of using a quadratic polynomial).

CRUP entropy had a significant inhibitory linear effect, in interaction with stimulus type (CRUP vs. Control). Figure 3 shows this interaction. As can be seen in the figure, Control words were more affected by entropy at this point through the word than CRUP words were.

Late entropy emerged as a nonlinear predictor, represented in the model by a quadratic term. As can be seen in Figure 4, items with higher late entropy values were recognized more quickly than those with lower late entropy values. The curvature in the left side of the graph suggests a floor effect.

Morphological family size had a facilitative effect on RTs, as expected based on the growing literature on family size in visual processing. However, its effect was nonlinear, and its quadratic term interacted with stimulus type (CRUP vs. Control). Figure 5 shows the effects of family size (linear, quadratic, and the interaction) in the model. In general, we see the concave curvature that was evident in the pre-CRUP entropy plot (Figure 2), but it is also apparent that CRUP words and Control words are differentially affected by family size for all but the smallest families. For the Control words, the facilitative effect of family size levels off, while for CRUP words, we observe inhibition for larger families.

We also did some analyses specific to the CRUP words, as there is one covariate that is specific to the CRUP words: the CRUP-to-UP distance, which is the difference (in milliseconds) between the CRUP and UP locations within a CRUP word. Note that this distance is 0 for Control words. CRUP-to-UP distance was found to have a linear relationship with overall item RT in English (Wurm & Ross, 2001), and we wanted to see if this also held for Dutch. Figure 6 shows that the simple bivariate relationship does hold. As is clear from the figure, there is a significant correlation between these two variables: Greater CRUP-to-UP distances are associated with faster RTs.

We therefore fitted a regression model to the RTs for CRUP words that included not only the regressors we examined in the full data set, but also CRUP-to-UP distance. The results of this analysis are shown in Table 5. In general the results look similar to the overall analysis. CRUP-to-UP distance was not significant as a main effect in this analysis, but it did interact with word frequency as shown in Figure 7. This conditioning plot (Cleveland, 1993) graphs log RTs as a function of CRUP-to-UP distance, for subsets of the data (with equal numbers of data points) that differ on word frequency. Frequency increases as one proceeds from the lower left panel to the right and then on the upper row of panels from left to right. The results indicate that there is very little effect of CRUP-to-UP distance for words with the lowest frequencies, but that as word frequency increases, a strong facilitative effect of CRUP-to-UP distance emerges.

Discussion

Although the current study did not replicate the overall CRUP word RT advantage that has been observed in English, there is evidence of differential processing between CRUP words and Control words. It is interesting to note that Control words are more sensitive to the effects of CRUP entropy (Figure 3) and family size (Figure 5). One possibility is that processing of CRUP words is less affected by these variables because it is more affected by something else (i.e., having passed the CRUP, which may result in the formation of a more restricted conditional hypothesis). It is also worth noting that the family size figure contains an interaction that goes in the opposite direction as any CRUP advantage that might have been there.

Another possibility for why an overall CRUP advantage was not observed is suggested by Figure 6, where we can see that the values for CRUP-to-UP distance in Dutch are only about half as large as those in English. It is possible that the main effect observed in English requires more time to build than is allowed by these shorter temporal distances. We were able to assess this hypothesis by reanalyzing the Wurm and Ross (2001) lexical decision time data, restricting the analysis to those CRUP words with CRUP-to-UP distances less than 250 msec. When we did this, the previously significant CRUP advantage shrank by two-thirds, and was no longer significant. It bears repeating that CRUP-to-UP distance *did* matter in the processing of Dutch CRUP words, though this was true only for words that were not very low in surface frequency (see Figure 7).

The other major contribution of the current study has to do with our examination of the effects of different information sources at different points throughout the words. Our interpretation of the results is based on the idea that different kinds of information (as indexed by the entropy measures and morphological family size) can be more or less useful at different points in the overall disambiguation process involved in spoken word recognition.

The entropy measures and morphological family size can be taken as indices of overall lexical activation. The information coin has two sides, though. On one hand, high values of entropy can be interpreted by the perceptual system as strong support for the lexicality of a stimulus, which can in principle speed performance in the lexical decision task. On the other hand, when many word candidates are active, the perceptual system must at some point get rid of the unintended ones (by decay of activation levels, active inhibition, or some other mechanism). It seems likely that disambiguating will be more difficult when there are more viable candidates with more similar frequencies (activation levels).

What we see in the results is that high entropy values early in a word (i.e., pre-CRUP entropy) lead to facilitation. This is because higher entropy indicates more (and/or more frequent) competitors, which we believe leads the perceptual system quickly toward a "Word" decision. This entropy measure was calculated two phonemic segments past the prefix, so it is possible that the perceptual system has just provisionally recognized what might be a prefix. A low entropy value in this case means very little "cohort" activity and less evidence of lexicality, so processing is relatively slow. At this relatively early part of a word, a higher entropy value is actually a beneficial thing.

The CRUP entropy effect in Figure 3 behaves differently. These entropies were calculated at a point later than the pre-CRUP entropies, and it seems that a prolonged high degree of lexical competition indicates unresolved ambiguity. Higher entropy implies the same high evidence of lexicality that we noted above, but it is possible that now the system is at a point where it is attempting to winnow the cohort to a single candidate. Pure lexicality information is not as helpful because something more specific is needed. More competition is decidedly not good in this case, and therefore RTs are slower. Importantly, CRUP word RTs are not slowed as much by this, possibly because disambiguation is occurring on the basis of the more restricted conditional lexical hypothesis established at the CRUP. That is, more information about word identity may be available for CRUP words than for Control words at this position.

Another few segments later, we once again see a facilitative effect of entropy (late entropy, shown in Figure 4). This is the entropy calculated at word end, and the reason that the effect of high late entropy is facilitative probably is that the remaining uncertainty here consists of continuation forms of the word candidate itself. Higher late entropy implies more of these forms, and more activation in this particular morphological cohort. Note that the entropies themselves are fairly low here. At this point in the stimulus, the perceptual system can be quite certain which morphological family is in question, so once again general lexicality information can speed responding. We believe that disambiguation is just about completed, and the remaining cohort members begin to act like a facilitative family size effect.

This interpretation receives support from the family size effect (Figure 5). It is noteworthy that family size emerges in our stepwise regression analysis as the crucial predictor, rather than root frequency, even though the two measures are highly correlated (see Table 2). When root frequency is added to the model described in Table 4, its coefficient is not significantly different from zero ($p > .3$), while the linear and quadratic coefficients of family size remain highly significant ($p < .0001$). We conceptualize the family size effect as an index of post-access resonance between morphologically and semantically related words (see, e.g., De Jong, Schreuder, & Baayen, 2003), supporting lexicality and yes-responses in lexical decision. For CRUP words, where a higher degree of disambiguation is hypothesized to be reached early on, there is less functionality for family resonance as a way of supporting a "Word" response. We think the inhibition observed for CRUP words when morphological families become very large may arise precisely because lexical disambiguation has progressed much farther for these words. Consequently, the advantage of more support from the morphological family for lexicality is outweighed by the disadvantage of having to discriminate between the target itself and its morphologically related competitors. We hypothesize that the absence of inhibition for the control words is due to the disambiguation process not having progressed as far as for the CRUP words, so that the disadvantage of disambiguating within the family does not (yet) outweigh the advantage of more support for lexicality.

Returning to the specific processing of CRUP words, we believe that there are several possibilities for interpreting the interaction of CRUP-to-UP distance with frequency shown in the conditioning plot of Figure 7. One formulation of the mechanism by which CRUPs operate uses the metaphor of special, restricted "lists" of roots that have combined with a particular prefix in the past. Items with very low surface frequencies are thus combinations that may not be familiar enough for the root to be included in the prefix-conditioned list. A related way of putting this is that listeners know more about the specific combinatorial histories of morphemes the more frequently they have been encountered together, and it is in medium- to high-frequency cases that the CRUP-to-UP distance information can be meaningfully used. Another possibility is to note that the higher the frequency of a prefixed word, the more likely it is to be the highest-frequency word in the cohort of words beginning with that prefix. Hence, a high-frequency prefixed word is less likely to suffer from competition from other members in the cohort. In other words, a large CRUP-to-UP distance may not offer much help to a low-frequency prefixed word simply because it suffers so much lexical competition from other prefixed words with free roots.

General Discussion

The current study had two primary purposes. One was to see if the RT advantage for CRUP words over Control words would extend to Dutch. In terms of the main effect, it did not. The whole notion of CRUPs will not translate equally well to all other languages, and in fact, Dutch did not offer a tremendous number of CRUP words because of the lower incidence of pseudoprefixation compared to English. Figure 6 and our reanalysis of data from Wurm and Ross (2001) suggest that our failure to find a main effect might be due in part to the limited range of CRUP-to-UP distances offered by Dutch. In English, with distances twice as large, the main effect is significant (Wurm & Aycock, 2003; Wurm & Ross, 2001). However, the current study did provide evidence that the CRUP is a perceptually meaningful point in a prefixed Dutch word. Larger CRUP-to-UP distances were related to faster RTs, for words that were not low in frequency (Figure 7). Additional evidence that the CRUP is perceptually meaningful comes from the significant interactions between this factor and CRUP entropy (Figure 3) and morphological family size (Figure 5).

To our knowledge, this study is the first to demonstrate the relevance of entropy measures at different locations in the root for probing the complexities of auditory disambiguation. One of the strongest conclusions we wish to draw from the current study is that both sides of the information coin need to be examined carefully. High entropy cannot be declared to be either a bad thing or a good thing in terms of processing ease. Rather, it depends on the point in processing that is being addressed, whether the word is a CRUP word, and additional factors such as the identities of the remaining candidates and the participant's task. For lexical decision, a high entropy at the beginning of the word appears to shorten RTs, probably because it supports the word's lexicality. Later in the word, a high entropy delays lexical decision, because a high entropy implies severe lexical competition. Much more work remains to be done in examining the effects of entropy, but it is clear that any model that hopes to accurately capture the process of word recognition will need to consider these influences. The predictive value of the late entropy measure shows, moreover, that it is possible and necessary to take the presence of morphological continuation forms into account within cohort-based analyses.

The present study is also the first to document a morphological family size effect for complex words in auditory processing. The fact that the variable's effect was not limited to the expected linear main effect and its interaction with stimulus type (CRUP vs. Control) suggests a need for a fairly complex explanatory framework. Nonlinearities have also been observed for visual lexical decision data (cf. Baayen, in press). The present data suggest that the support for lexicality provided by large morphological families may be offset by greater difficulty in disambiguation within these families, especially so when the disambiguation process is nearing completion, as witnessed by the stimulus type x family size interaction (Figure 5).

Thus far, we have interpreted the CRUP effect along the lines of the dual route mechanism of Wurm (1997), but it can probably be accommodated in other frameworks as well. Consider, for instance, metrical theory segmentation theory (Cutler & Norris, 1988; Cutler & Butterfield, 1992). In this theory, the stressed initial syllable of the root triggers a new lexical hypothesis at the offset of the prefix. If we assume that the likelihood of positing a lexical hypothesis for a given root is proportional to the number of different contexts in which that root appears, a facilitatory CRUP effect is expected. For free roots, which may be preceded not only by other prefixes (a property they share with bound roots) but also by a range of other linguistic forms such as pronouns and modals (a property unique to free roots), the likelihood of positing a lexical hypothesis is high. Conversely, for bound roots, this likelihood is low. Under these assumptions, there will be less lexical competition for CRUP words compared to their controls. Consider, e.g., the case in which a CRUP word and its matched control have the same number of cohort competitors at the moment in time that sufficient information has become available to conclude that the root is stressed so that new lexical hypotheses can be initiated at root onset (prefix offset). The number of such hypotheses will be lower for the CRUP word than for its matched control. This is so because in the case of a CRUP word there is, by definition, at least one bound root in the cohort for which a new lexical hypothesis is unlikely to be entertained. Hence, the CRUP word will suffer less lexical competition, allowing faster lexical disambiguation and shorter response latencies in auditory lexical decision.

We conclude that the CRUP is a psychologically real construct that is not language-specific. It appears to be one piece of information that can be useful to the perceptual system, as a main effect under some circumstances and in interaction with other variables under other circumstances. The CRUP does not exert a dominant influence on processing in Dutch the way it appears to for English, but the perceptual system is nevertheless sensitive to this information.

References

Baayen, R.H. (1994). Productivity in language production. *Language and Cognitive Processes, 9,* 447-469.

Baayen, R.H. (2004). Statistics in psycholinguistics: A critique of some current gold standards. *Mental Lexicon Working Papers, 1,* 1-45.

Baayen, R.H. (in press). Data mining at the intersection of psychology and linguistics. To appear in A. Cutler (Ed.), *Twenty-first century psycholinguistics: Four cornerstones.* Mahwah, NJ: Erlbaum.

Baayen, R.H., Dijkstra, T., & Schreuder, R. (1997). Singulars and plurals in Dutch: Evidence for a parallel dual-route model. *Journal of Memory and Language, 37,* 94-117.

Baayen, R.H., Piepenbrock, R., & Gulikers, L. (1995). The CELEX Lexical Database (CD-ROM). Philadelphia: Linguistic Data Consortium, University of Pennsylvania.

Baayen, R.H., Tweedie, F.J., & Schreuder, R. (2002). The subjects as a simple random effect fallacy: Subject variability and morphological family effects in the mental lexicon. *Brain and Language, 84,* 55-65.

Bertram, R., Baayen, R.H., & Schreuder, R. (2000). Effects of family size for complex words. *Journal of Memory and Language, 42,* 390-405.

Cleveland, W.S. (1993). *Visualizing data.* Summit, NJ: Hobart Press.

Coolen, R., van Jaarsveld, H., & Schreuder, R. (1991). The interpretation of isolated novel nominal compounds. *Memory and Cognition, 19,* 341-352.

Cutler, A., & Butterfield, S. (1992). Rhythmic cues to speech segmentation: Evidence from juncture misperception. *Journal of Memory and Language, 31,* 218-236.

Cutler, A., & Norris, D.G. (1988). The role of strong syllables in segmentation for lexical access. *Journal of Experimental Psychology: Human Perception and Performance, 14,* 113-121.

de Jong, N.H., Schreuder, R., & Baayen, R.H. (2000). The morphological family size effect and morphology. *Language and Cognitive Processes, 15,* 329-365.

de Jong, N.H., Schreuder, R., & Baayen, R.H. (2003). Morphological resonance in the mental lexicon. In R.H. Baayen & R. Schreuder (Eds.), *Morphological structure in language processing* (pp. 65-88). Berlin: Mouton de Gruyter.

Gaskell, M.G., & Marslen-Wilson, W.D. (1997). Integrating form and meaning: A distributed model of speech perception. *Language and Cognitive Processes, 12,* 613-656.

Harrell, F.E. (2001). *Regression modeling strategies.* New York: Springer.

Henderson, L. (1985). Toward a psychology of morphemes. In A.W. Ellis (Ed.), *Progress in the psychology of language* (vol. 1, pp. 15-72). Hillsdale, NJ: Lawrence Erlbaum Associates.

Kemps, R., Wurm, L.H., Ernestus, M., Schreuder, R., & Baayen, R.H. (in press). Prosodic cues for morphological complexity: Comparatives and agent nouns in Dutch and English. *Language and Cognitive Processes.*

Kostić, A., Marković, T., & Baucal, A. (2003). Inflectional morphology and word meaning: Orthogonal or co-implicative cognitive domains? In R.H. Baayen & R. Schreuder (Eds.), *Morphological structure in language processing* (pp. 1-43). Berlin: Mouton de Gruyter.

Marslen-Wilson, W.D. (1984). Function and process in spoken word recognition. In H. Bouma & D.G. Bouwhuis (Eds.), *Attention and performance: Control of language processes* (vol. X, pp. 125-150). Hillsdale, NJ: Lawrence Erlbaum Associates.

Marslen-Wilson, W., & Welsh, A. (1978). Processing interactions and lexical access during word recognition in continuous speech. *Cognitive Psychology, 10,* 29-63.

Moscoso del Prado Martín, F., Kostić, A., & Baayen, R.H. (in press). Putting the bits together: An information theoretical perspective on morphological processing. *Cognition.*

Pinheiro, J.C., & Bates, D.M. (2000). *Mixed-effects models in S and S-PLUS.* New York: Springer.

Schreuder, R., & Baayen, R.H. (1997). How complex simplex words can be. *Journal of Memory and Language, 37,* 118-139.

Schreuder, R., & Flores d'Arcais, G.B. (1989). Psycholinguistic issues in the lexical representation of meaning. In W.D. Marslen-Wilson, (Ed.), *Lexical representation and process* (pp. 409-436). Cambridge, MA: M.I.T. Press.

Tyler, L.K., Marslen-Wilson, W.D., Rentoul, J., & Hanney, P. (1988). Continuous and discontinuous access in spoken word-recognition: The role of derivational prefixes. *Journal of Memory and Language, 27,* 368-381.

Tyler, L.K., Moss, H.E., Galpin, A., & Voice, J.K. (2002). Activating meaning in time: The role of imageability and form-class. *Language and Cognitive Processes, 17,* 471-502.

Wurm, L.H. (1997). Auditory processing of prefixed English words is both continuous and decompositional. *Journal of Memory and Language, 37,* 438-461.

Wurm, L.H., & Aycock, J. (2003). Recognition of spoken prefixed words: The role of early Conditional Root Uniqueness Points. In R.H. Baayen & R. Schreuder (Eds.), *Morphological structure in language processing* (pp. 259-286). Berlin: Mouton de Gruyter.

Wurm, L.H., & Ross, S.E. (2001). Conditional root uniqueness points: Psychological validity and perceptual consequences. *Journal of Memory and Language, 45,* 39-57.

Appendix

Critical Stimuli

CRUP words

behelp	bə-'hɛlp	'make do'
benut	bə-'nʏt	'utilize'
bevecht	bə-'vɛxt	'fight'
bewoon	bə-'ʋon	'inhabit'
bezuip	bə-'zœyp	'get drunk'
gebeten	xə-'betə	'bitten'
gedram	xə-'drɑm	'nagging'
genummerd	xə-'nʏmərt	'numbered'
gepost	xə-'pɔst	'posted'
geprikt	xə-'prɪkt	'pricked'
gewed	xə-'ʋɛt	'bet'
gezind	xə-'zɪnt	'disposed'
ontval	ɔnt-'fɑl	'let slip'
vergok	vər-'xɔk	'gamble away'
vergun	vər-'xʏn	'permit'
verhonger	vər-'hɔŋər	'starve'
verschoon	vər-'sxon	'change'
verslap	vər-'slɑp	'relax'
versleep	vər-'slep	'drag'

verwelk	vər-'ʋɛlk	'wilt'

Control words

bespan	bə-'spɑn	'stretch'
belet	bə-'lɛt	'prevent'
beheks	bə-'hɛks	'bewitch'
bewaak	bə-'ʋak	'guard'
behaag	bə-'hax	'please'
gebeden	xə-'bedə	'prayed'
geklit	xə-'klɪt	'sticking together'
gewaggeld	xə-'ʋɑxəlt	'tottered'
gespit	xə-'spɪt	'dug'
geknipt	xə-'knɪpt	'cut'
gebel	xə-'bɛl	'ringing'
gemoord	xə-'mort	'murdered'
ontzeg	ɔnt-'sɛx	'refuse'
verkas	vər-'kɑs	'relocate'
vergal	vər-'xɑl	'spoil'
verbitter	vər-'bɪtər	'embitter'
verkleur	vər-'klør	'discolor'
verklap	vər-'klɑp	'give away'
verslaap	vər-'slap	'sleep away'
verwond	vər-'ʋɔnt	'injure'

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Table 1

Summary Statistics (Means and SEMs) for Critical Stimuli

	Stimulus group	
Stimulus characteristic	CRUP words	Control words
Word frequency[a]	51 (19.9)	58 (28.8)
Root frequency[a]	5412 (1669)	8914 (6870)
Duration (msec)	707 (18.2)	726 (17.1)
Pre-CRUP entropy	2.24 (0.16)	2.25 (0.13)
CRUP entropy	1.45 (0.13)	1.67 (0.16)
Late entropy	0.80 (0.14)	0.85 (0.15)
Family size	44 (10.3)	28 (6.5)

[a]per 42 million tokens, from the CELEX database (Baayen et al., 1995).

Note. None of the stimulus-group differences approached significance (all *p*s > .28).

Table 2

Regressor Intercorrelations

	Root freq.	Family size	Duration	Entropy		
				Pre-CRUP	CRUP	Late
Word frequency[a]	.03	.13	-.25	-.11	-.33*	-.14
Root frequency[a]		.60***	-.13	-.13	.00	.22
Family size			-.15	-.10	-.04	.18
Duration				.04	-.04	.11
Pre-CRUP entropy					.13	.29
CRUP Entropy						.49**

[a]per 42 million tokens, from the Dutch portion of the CELEX database (Baayen et al., 1995).

$^{*}p < .05$ $^{**}p < .01$ $^{***}p < .001$

Table 3

Lexical Decision Times (in msec) and Error Rates

Stimulus type	Mean RT (*SEM*)	Mean error rate
CRUP words	643 (9.6)	.12
Control words	659 (11.0)	.16

Table 4

Summary of Analysis for Variables Predicting Log Reaction Time (All Items)

Variable	*B*	*SE(B)*	β	*df*	*F*
Main effects					
Position	-0.0003	0.0001	-0.063	1,1156	8.76^{**}
Prefix	--	--	--	3,1156	7.31^{***}
Word frequency	-0.0432	0.0069	-0.203	1,1156	39.23^{***}
Pre-CRUP entropy	-0.9360	0.1289	-1.419	1,1156	52.76^{***}
Pre-CRUP entropy (quadratic)	0.1956	0.0287	1.327	1,1156	46.34^{***}
CRUP entropy	0.1407	0.0297	0.205	1,1156	22.43^{***}
Late entropy (quadratic)	-0.1342	0.0114	-0.381	1,1156	138.05^{***}
Family size	-0.2536	0.0541	-0.636	1,1156	21.94^{***}
Family size (quadratic)	0.0444	0.0086	0.701	1,1156	26.81^{***}
Interactions with Stimulus type					
CRUP entropy	--	--	--	1,1156	19.99^{***}
Family size (quadratic)	--	--	--	1,1156	5.49^{*}

$^{*}p < .05$. $^{**}p < .01$. $^{***}p < .001$.

Table 5

Summary of Analysis for Variables Predicting Log Reaction Time (CRUP Words Only)

Variable	*B*	*SE(B)*	*β*	*df*	*F*
Main effects					
Position	-0.0003	0.0001	-0.065	1,585	4.79*
Prefix	--	--	--	3,585	11.09***
Pre-CRUP entropy	-0.6640	0.1818	-1.176	1,585	13.34***
Pre-CRUP entropy (quadratic)	0.1319	0.0427	1.038	1,585	9.55**
CRUP entropy	0.0803	0.0364	0.106	1,585	4.87*
Late entropy (quadratic)	-0.1294	0.0277	-0.352	1,585	21.75***
Family size	-0.4330	0.1298	-1.194	1,585	11.12***
Family size (quadratic)	0.0727	0.0207	1.344	1,585	12.34***
Word frequency x					
CRUP-to-UP distance	-0.0003	0.0001	-0.241	1,585	28.63***

*p < .05. **p < .01. ***p < .001.

Figure Captions

Figure 1. An example CRUP word and an example Control word. CRUP means "Conditional Root Uniqueness Point" and UP means "Uniqueness Point." CRUP words are those in which the CRUP precedes the UP.

Figure 2. Log reaction time (in msec) as a function of pre-CRUP entropy (in bits).

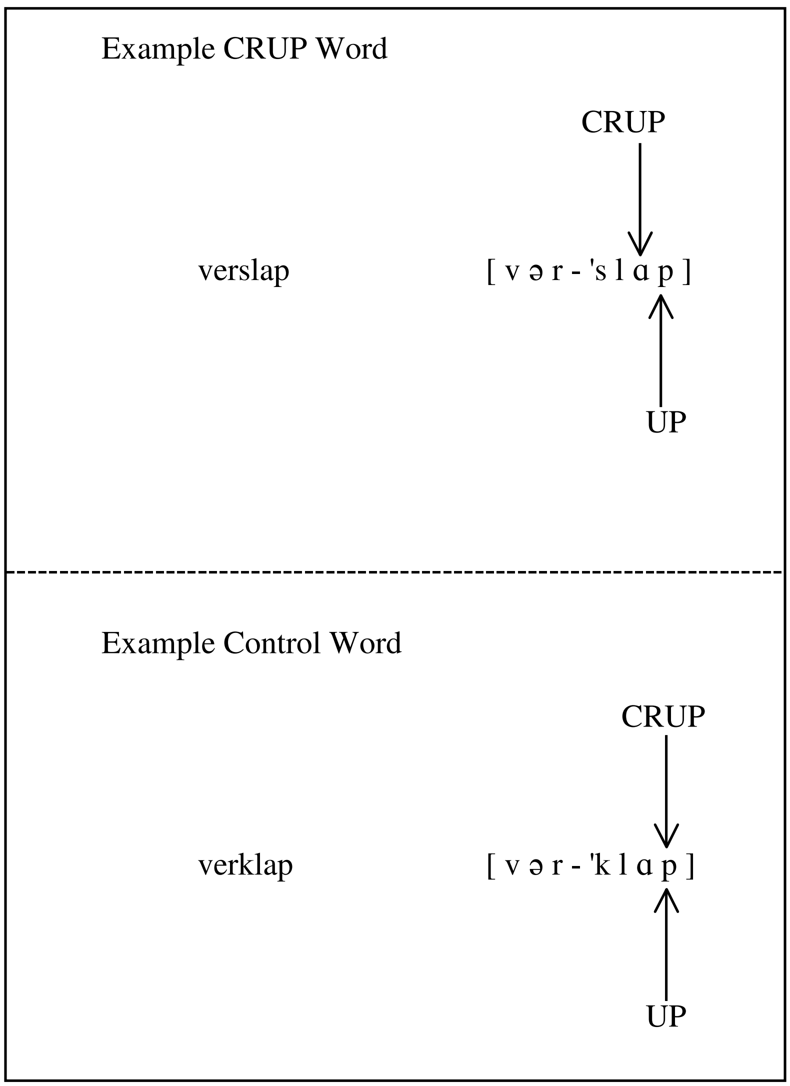
Figure 3. Log reaction time (in msec) as a function of CRUP entropy (in bits). The solid line shows the function for CRUP words and the dashed line shows the function for Control words.

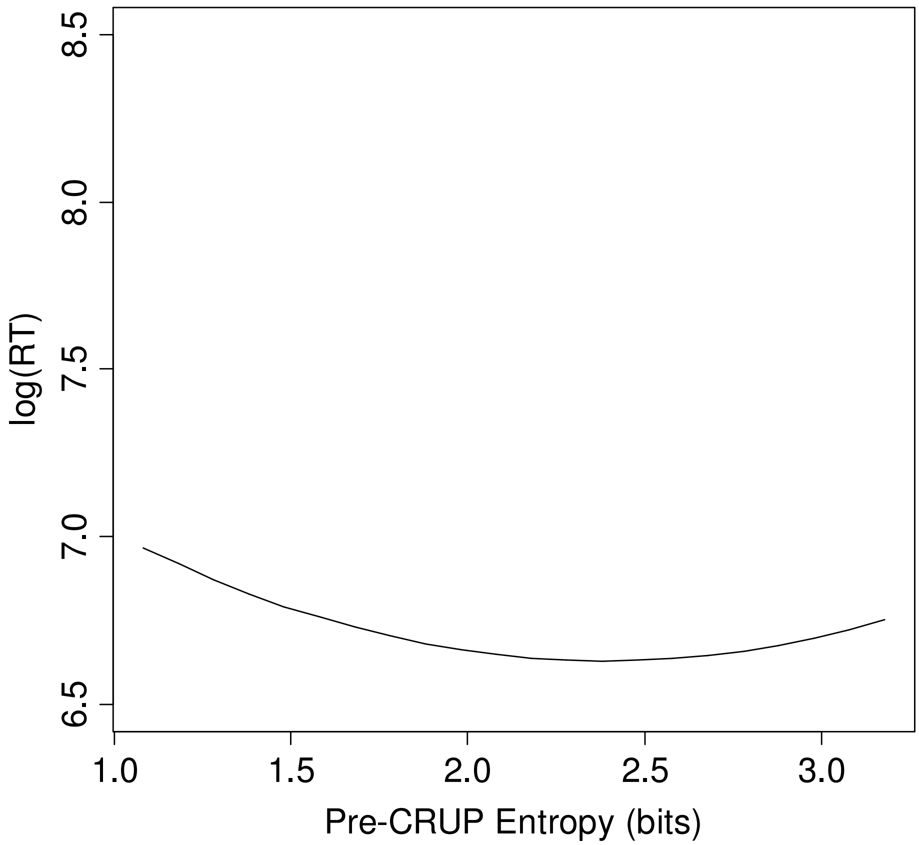
Figure 4. Log reaction time (in msec) as a function of late entropy (in bits).

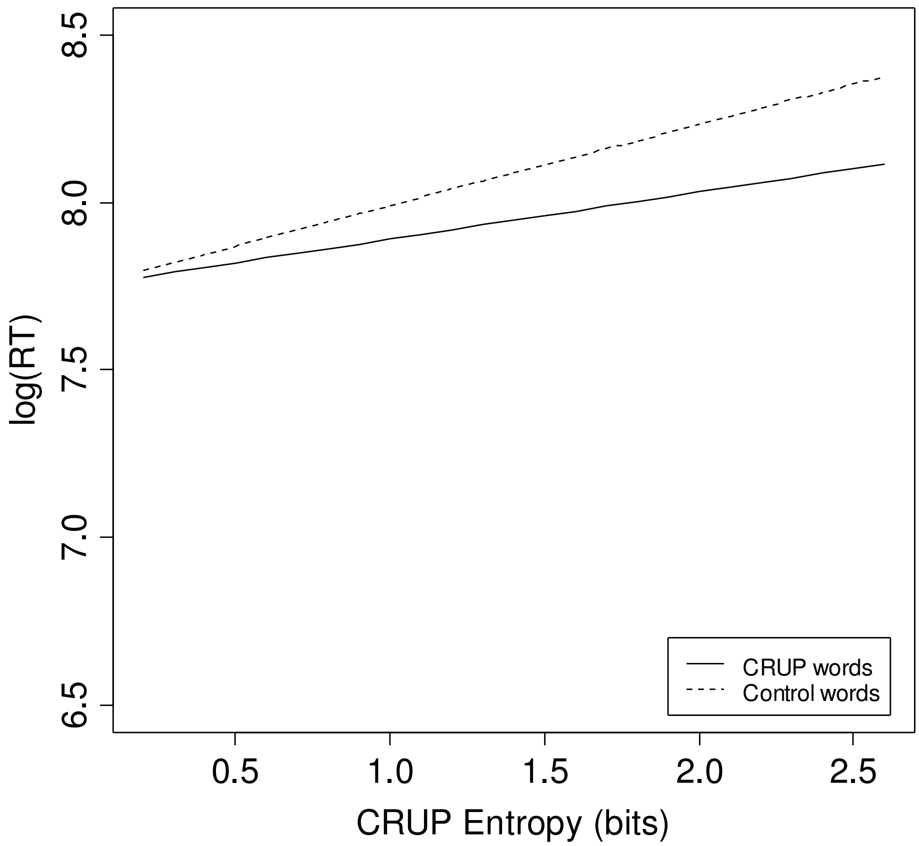
Figure 5. Log reaction time (in msec) as a function of log morphological family size. The solid line shows the function for CRUP words and the dashed line shows the function for Control words.

Figure 6. Mean lexical decision time (in msec) as a function of CRUP-to-UP distance (in msec). The left panel shows data from the current study. The right panel shows the lexical decision data from Wurm and Ross (2001).

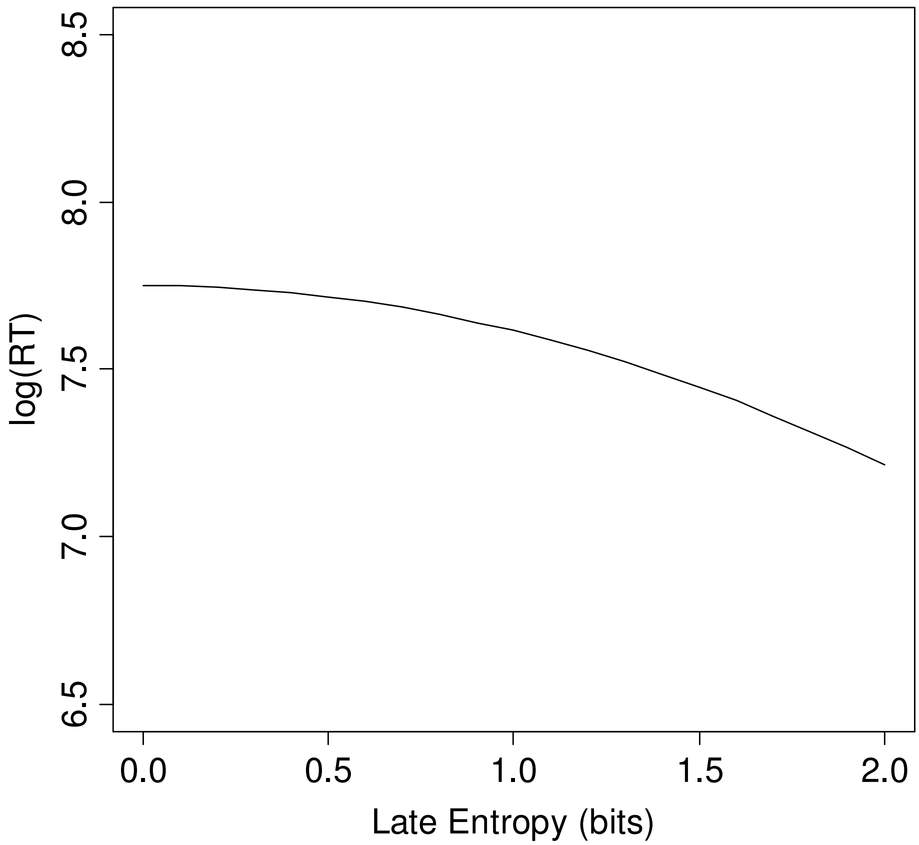
Figure 7. Log reaction time (in msec) as a function of word frequency and CRUP-to-UP distance (in msec). Data are for CRUP words only.

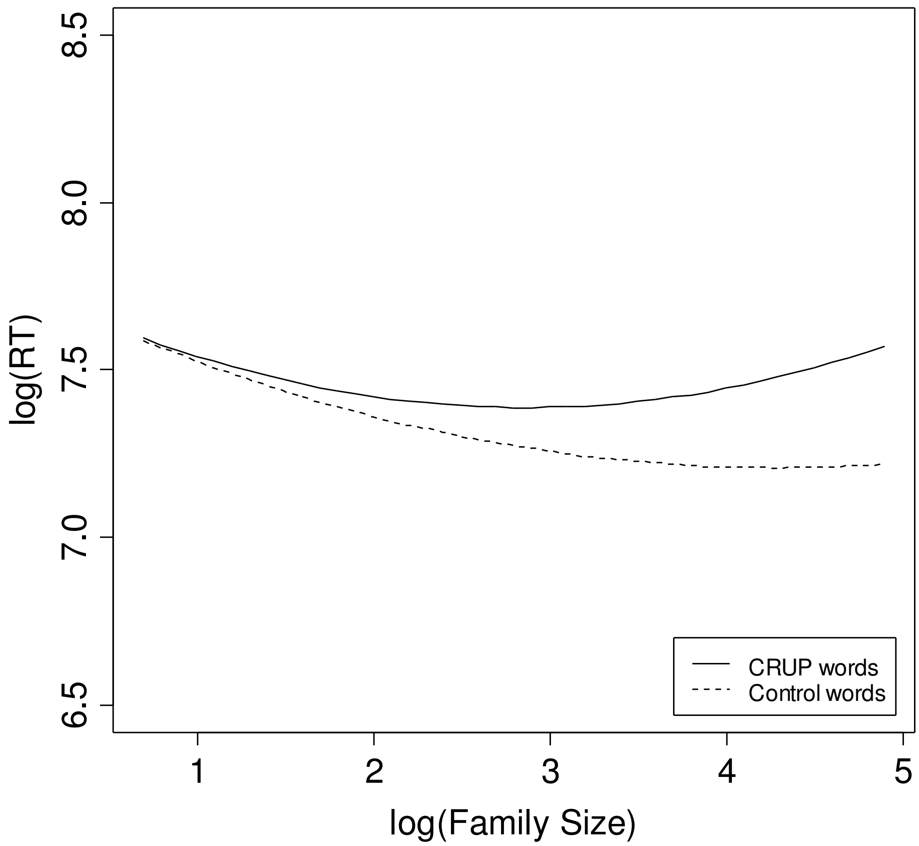

Example CRUP Word
CRUP
verslap
[v ə r - 's l ɑ p]
UP
Example Control Word
CRUP
verklap
[v ə r - 'k l ɑ p]
UP

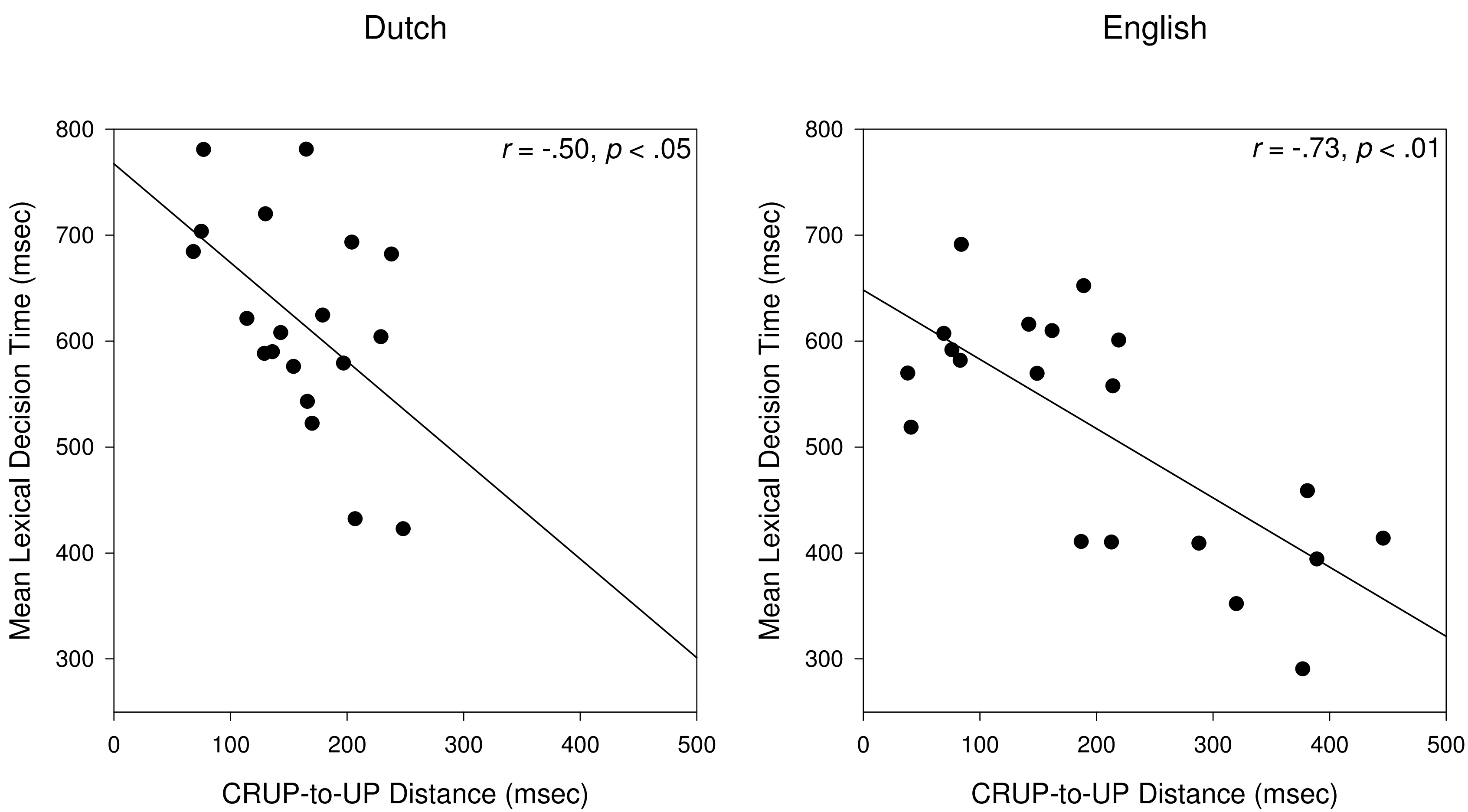

8.5
8.0
7.5
7.0
6.5
log(RT)
1.0
1.5
2.0
2.5
3.0
Pre-CRUP Entropy (bits)

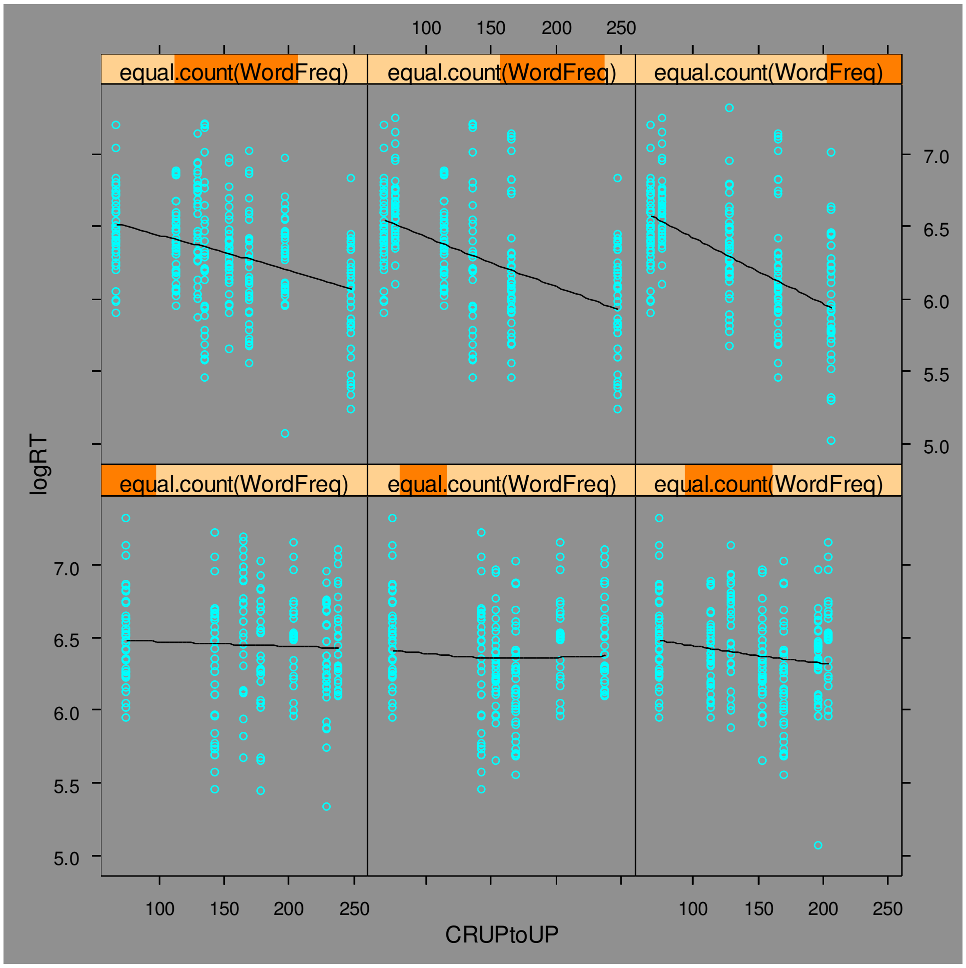


log(RT)
8.5
8.0
7.5
7.0
6.5
0.5
1.0
1.5
2.0
2.5
CRUP Entropy (bits)
CRUP words
Control words


8.5
8.0
7.5
7.0
6.5
log(RT)
0.0
0.5
1.0
1.5
2.0
Late Entropy (bits)


8.5
8.0
7.5
7.0
6.5
log(RT)
1
2
3
4
5
log(Family Size)
CRUP words
Control words


Dutch
English
r = -.50, p < .05
r = -.73, p < .01
Mean Lexical Decision Time (msec)
Mean Lexical Decision Time (msec)
CRUP-to-UP Distance (msec)
CRUP-to-UP Distance (msec)
800
700
600
500
400
300
0
100
200
300
400
500


equal.count(WordFreq)
equal.count(WordFreq)
equal.count(WordFreq)
equal.count(WordFreq)
equal.count(WordFreq)
equal.count(WordFreq)
logRT
CRUPtoUP
100
150
200
250
5.0
5.5
6.0
6.5
7.0