Does English Coronal Place Assimilation Create Lexical Ambiguity?

David W. Gow Jr.
Massachusetts General Hospital and Salem State College

The purpose of this study was to determine how potential lexical ambiguity produced by place assimilation is resolved. Four cross-modal form priming experiments using primes in sentential contexts were performed. In the first 2, prime items had underlyingly coronal offsets (e.g., right) with assimilated noncoronal place. The primes were judged to be perceptually ambiguous (between right and ripe) in Experiment 1 and noncoronal (ripe) in Experiment 2 in off-line testing. In Experiment 3, primes were replaced with corresponding underlyingly noncoronal items (ripe). In all 3 experiments, participants showed selective priming for the underlying form of the prime. A 4th form priming experiment using the gated tokens of priming stimuli used in Experiment 2 examined the role of postlexical context on this process. In this experiment, participants showed priming for both underlying and surface forms of the prime.

Assimilation is one of several productive phonological processes that can change the way a word is pronounced. In English place assimilation, a syllable-final coronal segment may take the place of articulation of a consonant that immediately follows it (Chomsky & Halle, 1968). For example, the coronal segment /t/ in the word right may be pronounced like /p/ when it is followed by a labial segment; that is, the /bv in right berries could produce, instead of right /s\f, an item that sounds like the word ripe [rɪp]. This article explores the questions of whether and how listeners ultimately determine which word they heard in these modification-inducing contexts.

Several researchers have demonstrated that assimilation does not disrupt word recognition in instances in which the modification fails to produce potential lexical ambiguity (Gaskell & Marslen-Wilson, 1996; Gow, 2001; Marslen-Wilson, Nix, & Gaskell, 1995). For example, listeners hearing green beans successfully access green beans.

Assimilation may pose greater problems when there is potential lexical ambiguity. For the most part, researchers have accepted the notion that assimilation can produce a neutralizing feature change. By this account, a token of right in the phrase right berries may be perceptually indistinguishable from a token of the word ripe. This means that listeners cannot hear the underlying form of an assimilated token and must use special representational or inferential mechanisms to access it (Gaskell, Hare, & Marslen-Wilson, 1995; Gaskell & Marslen-Wilson, 1996, 1998; Lahiri & Marslen-Wilson, 1991).

Research into the articulation and spectral form of assimilated tokens suggests that another characterization of assimilation may be appropriate. Assimilation appears to produce a range of modification rather than discrete feature change. Electropalatographic studies by Barry (1985), Kerswill (1985), and Nolan (1992) showed that speakers may create simultaneous coronal and noncoronal closures when producing place-assimilated, underlyingly coronal segments. This evidence may underestimate the degree of residual coronal articulation involved in these gestures, as it reflects only contact between articulators. Articulation that involves constriction without full contact between articulators could have acoustic consequences without being reflected by electropalatographic measurement.

In the acoustic domain, several studies show that place assimilation may be realized acoustically as an intermediate form between those associated with coronal and noncoronal place. Holst and Nolan (1995) have shown that place assimilation of word-final fricatives may lead to the production of segments with frication envelopes showing a blending of alveolar and palatoalveolar place characteristics. However, they noted that in many instances, assimilation of coronal segments leads to the creation of a spectral envelope that is consistent with noncoronal place. This result suggests that although assimilatory modification is graded, it may sometimes lead to discrete change. Nonetheless, it is possible that subtler measurements, such as spectral tilt, could reveal incomplete rather than discrete feature change. Gow and Hussami (1999) compared the formant transitions associated with minimal triplets of assimilated underlying coronals, unmodified coronals, and underlying noncoronals and found evidence of a significant three-way distinction, with assimilated items showing a pattern of formant movement that was intermediate between the patterns associated with unmodified coronal and noncoronal place. At a minimum, both studies suggested that assimilation produces a range of degrees of acoustic modification.

Listeners might perceive this range in several ways. If phoneme perception is strictly categorical, listeners may arbitrarily break
this continuum into three discrete categories (velar, coronal, and labial). If this is the case, context-sensitive mapping or a special representational or inferential mechanism for recognizing assimilated words would be needed. It is conversely possible that listeners recognize partial or ambiguous assimilation as an additional category between pure coronal and velar or labial place. If this is the case, listeners may be able to recognize the underlying form of a modified item on the basis of the observation that these intermediate forms can be created only through the assimilation of underlyingly coronal place and thus must be underlyingly coronal. Although there is no direct evidence that this is the case, there is indirect behavioral evidence that assimilatory modification provides listeners with signs of modification that are not provided by deliberate, discrete feature change. Gaskell and Marslen-Wilson (1998) and Gow (2001) performed phoneme monitoring experiments aimed at determining whether listeners use assimilation to anticipate the segments that trigger assimilation. In both experiments, participants monitored for the word-initial phoneme targets that immediately followed word-final instances of nonmodification versus appropriate or inappropriate place assimilation. The Gaskell and Marslen-Wilson study used stimuli that were deliberately pronounced with feature changes, whereas the Gow study used cross-spliced tokens of spontaneously assimilated items to create the three stimulus types. Gow significantly found facilitated target detection following valid assimilation as compared with target detection following unmodified word forms, whereas Gaskell and Marslen-Wilson did not. This implies that the stimuli used in the two studies had different acoustic properties that supported alternative processing strategies; therefore, these results suggest that stimulus properties affect processing. The perceptual status of strongly assimilated tokens is, unfortunately, a largely open empirical question. To understand how listeners recognize the underlying forms of modified words, it is important for researchers to understand exactly how listeners perceive their acoustic realizations.

Activation-based models of word recognition such as TRACE (McClelland & Elman, 1986), shortlist (Norris, 1994; Norris, McQueen, & Cutler, 1995), and some versions of the cohort model (Marslen-Wilson, 1987) offer the simplest account of the mapping between recovered and stored features rather than the correspondence between recovered and stored features. Thus, the listener would reject \( \text{aIp} \) if it appeared before a coronal or velar segment. According to this model, \( \text{aIp} \) could not be a modified form of \( \text{ripe} \). If the activation mechanism is based on the degree of correspondence between recovered and stored features rather than the presence of mismatch, \( \text{ripe} \) might still be preferred over \( \text{right} \) because it matched one more feature. Lahiri (1998) opts for the former mechanism in the implementation of an underspecification-based model of word recognition. In this model, higher level constraints are called on to deactivate contextually inappropriate candidates. This general type of mechanism for selecting among a set of activated candidates is well motivated, as a variety of studies have demonstrated that listeners hearing homophones in context initially access all possible interpretations and then select the most appropriate interpretation for the given context (Onifer & Swinney, 1981; Seidenberg, Tanenhaus, Leiman, & Bienkowski, 1982; Swinney, 1981).

Gaskell and colleagues (Gaskell, 1994; Gaskell & Marslen-Wilson, 1996, 1998; Marslen-Wilson et al., 1995) suggested a different mechanism for coping with modification that could also lead to the activation of multiple lexical candidates. Gaskell and Marslen-Wilson (1996) suggested that listeners use a mechanism similar to underspecification to initially activate items that could potentially have been heard in modified form (e.g., \( \text{right} \) could potentially be realized as \( \text{jalp} \) in the phrase \( \text{right berries} \)), but then posit a second inferential step in which the listener may assess whether the potential modification could have taken place in the context in which it appears. For example, the \( \text{t/l in right} \) could assimilate labial place only before a labial such as \( \text{/p/, /b/, or /m/} \). Thus, \( \text{jalp} \) could not be a modified form of \( \text{right} \) if it appeared before a coronal or velar segment. According to this model, a listener would reject \( \text{jalp} \) as an instance of \( \text{right} \) in these contexts. Although such a mechanism could successfully discriminate between modified versions of \( \text{right} \) and unmodified tokens of \( \text{ripe} \) in many contexts, it would not discriminate between terms in contexts in which \( \text{jalp} \) was followed by a word beginning with a labial segment. This would presumably leave both items activated in
labial contexts. Similar to the underspecification model, the inferential model could appeal to a postlexical selection model to use higher order context to resolve the ambiguity.

Therefore, there are two ways of characterizing the phonetic modification caused by place assimilation. If assimilation leads to the complete change of a feature, then assimilation can potentially create lexical ambiguity of the right–ripe berries sort. The term lexical ambiguity is used in this article to describe only those cases in which more than one lexical candidate is fully activated at the offset of a word. Both underspecification (Lahiri & Marslen-Wilson, 1991) and inference accounts of spoken word recognition (Gaskell, 1994; Gaskell & Marslen-Wilson, 1996, 1998; Marslen-Wilson et al., 1995) predict that these types of stimuli should lead to the initial access of both lexical alternatives, at least in some contexts, and leave the problem of disambiguation to putative postlexical selection mechanisms. If assimilation involves modification that is distinguishable from both nonchange and complete change of a feature, then it does not have to lead to lexical ambiguity. Listeners should be able to selectively access the correct underlying form of an item without appealing to postlexical selection mechanisms.

The purpose of this study was to determine whether English postlexical coronal place assimilation can produce lexical ambiguity. By answering this question, I hoped to better characterize both assimilation and the processes that allow listeners to recognize spoken words in all of their manifestations. A series of form priming experiments were performed to determine the pattern of lexical activation that listeners produced after hearing potentially ambiguous words, such as right–ripe, in contexts that would support assimilation. In each experiment, participants heard either an assimilated word in a context that could potentially make it sound like another word (e.g., right berries) or an unassimilated word that might sound like an assimilated form of another word (e.g., ripe berries). In both conditions, form priming was used to determine which potential interpretations were activated (e.g., ripe and/or right). In the first two experiments, participants heard sentences containing prime items ending in underlying coronals with assimilated noncoronal place. An off-line perceptual task was used in pretesting so that I could select assimilated items from a large set of tokens on the basis of the degree to which they were modified. Experiment 1 used tokens that were judged to be perceptually ambiguous, whereas Experiment 2 used tokens that were judged to be perceptually noncoronal. Experiment 3 used the same sentence contexts as Experiment 2, but assimilated items, such as right, were replaced with corresponding underlyingly noncoronal items, such as ripe. Finally, a fourth experiment was performed to assess the role of postassimilation context on the recognition of assimilated speech. Similar to the other experiments, Experiment 4 used the form priming paradigm to examine the pattern of lexical activation produced by potentially ambiguous assimilated speech. This experiment was a modified replication of Experiment 2, using gated tokens of the same auditory stimuli but removing postassimilation context.

General Method and Materials

The four experiments reported in this article were aimed to determine the pattern of lexical activation produced by modified or potentially modified word forms presented in syntactically and semantically neutral sentential contexts. To do this, I used a cross-modal form priming paradigm. Form priming was originally developed by Tanenhaus, Flanigan, and Seidenberg (1980). It has been used extensively to examine lexical activation mechanisms and the nature of phonological representations in the lexicon (Zwitserlood, 1996). In my experiments, I used a variant of form priming in which participants heard a prime item in context and were then shown a lexical decision probe 100 ms after its offset, concurrent with the continuation of the prime’s carrier sentence. The 100-ms interstimulus interval was provided to account for the rise time of perceptual analysis and thus to ensure that lexical activation reflected processing of the offset of the prime (Zwitserlood & Schriefers, 1995). Priming effects were examined by comparing the reaction time and accuracy associated with the lexical decision on trials in which there was phonological similarity between primes and probes with that associated on trials in which the same probe was preceded by a prime item that was phonologically and semantically unrelated. When this paradigm is used with short interstimulus intervals and a large number of distractor trials to discourage strategic responding, listeners tend to show little tolerance for mismatch between prime and probe items (Marslen-Wilson, 1993). It therefore provides a reliable measure of form activation in spoken word recognition.

Phonologists historically tend to characterize phonological assimilation as a complete change from one feature value to another (cf. Chomsky & Halle, 1968; Kenstowicz, 1994). This characterization is also reflected in the method of stimulus creation used in a number of processing studies with experimentally aware speakers either intentionally assimilating or deliberately pronouncing words with full feature change to approximate assimilation (Gaskell & Marslen-Wilson, 1996, 1998). Given the assumption that assimilation produces discrete feature change, this method allowed researchers to avoid the potential pitfalls of cross-splicing techniques when examining the effects of contextually appropriate versus inappropriate feature change. However, if natural place assimilation is graded, results using such stimuli may overestimate the degree of lexical ambiguity that can be produced by naturally occurring assimilation.

In these experiments, all assimilation stimuli were produced spontaneously by an experimentally naive speaker. Spontaneous natural assimilation was chosen over deliberate or conscious assimilation, because acoustic and articulatory evidence cited earlier suggests that English place assimilation is characterized by continuous or graded feature change.

Because I chose to use spontaneously assimilated items as priming stimuli, it was important to determine the degree to which these tokens were modified. If assimilatory modification is realized along a continuum, then it is possible that more and less completely assimilated tokens are perceived differently. This problem was addressed through the use of extensive perceptual pretesting that enabled the selection of tokens showing a uniform degree of perceived modification.

Pretest

The auditory stimuli for the experiments reported in this article were initially derived from a set of 93 familiar, monosyllabic, open-class words ending in the coronal nasal /n/, or stops /k/ or /d/. All words had neighbors differing in the place of articulation of the word-final segment. For instance, the word right, which ends in the coronal stop /t/, had the neighbor ripe, which ends with the labial /p/. These words were placed in sentential contexts in which the following word began with a stop consonant that could induce the appropriate labial or velar assimilation. For example, the labial /b/ in berries triggers the labial assimilation of the /p/ to produce the surface form [tauIp] in the sentence This time she tried to get the right berries for her pie.

The stimulus sentences were read by an experimentally naive male speaker of a standard New England dialect of American English. The speaker was selected in part because his speech
showed strong and frequent assimilation on casual listening. He produced six tokens of each sentence, with the instruction to read them in a fluent and casual style. This produced a total of 588 tokens. The reader evidenced no conscious knowledge of the phenomenon of place assimilation. All sentences were read in a sound attenuating chamber and were recorded on a Sony TCD-D8 digital audiotape recorder at a sampling rate of 44.1 kHz, using a Sony ECM-9090A microphone. These tokens were transferred to a Power Macintosh computer, where they were downsampled to 32 kHz with 16-bit sound, volume equalized, and edited into individual sound files using the Soundedit 16 waveform manipulation software package (Version 2.0; Macromedia, San Francisco, CA).

All 588 sentence tokens were then subjected to a perceptual pretest to determine how listeners perceived the surface forms of the potential prime items. Twelve participants for the pretest, which was administered individually over two sessions, were drawn from the Neuropsychology Laboratory at the Massachusetts General Hospital and the Speech Communication Group of the Research Laboratory of Electronics at the Massachusetts Institute of Technology (MIT). Posttesting interviews revealed that none of the participants were aware of the phenomenon of English coronal place assimilation, or of the potential role of postsegment context. The participants heard each sentence token by itself. At the offset of the sentence, they were shown two words (e.g., RIGHT and RIPE) and were asked to rate the degree to which the surface form resembled the two alternatives on a 7-point scale. They were instructed that a rating of 1 meant that a word sounded unambiguously like the coronal alternative (e.g., right) and bore no resemblance to the noncoronal one (e.g., ripe). A rating of 7 meant that a word sounded unambiguously like the noncoronal alternative (e.g., ripe) and bore no resemblance to the coronal alternative (e.g., right). A score of 4 indicated that the token showed equal resemblance to each of the alternatives. This task significantly did not ask participants to make judgments about the underlying forms of these tokens. The question was created in these terms to draw a distinction between the methodological issue of how strongly modified the test tokens were and the theoretical issue of whether listeners were able to discern their underlying form. Ratings ranged from 1.0 to 6.8, with an overall mean rating of 3.0 across tokens tested. These rating scores provided the basis for selecting different sets of sentences and sentence tokens to serve as auditory stimuli in Experiments 1 and 2.

Experiment 1

Method

Participants. The participants were 28 members (16 women and 12 men) of the MIT community, with a mean age of 27.0 years. All were native speakers of standard dialects of American English with no discernible (uncorrected) deficit in vision or hearing. They were paid $8 for their participation in the study, with the opportunity to earn an additional $2 bonus, based on their performance over a subset of distractor trials in the lexical decision task and a memory test.

Stimuli. The auditory priming stimuli were constructed as described in the pretest section. From the initial 588 sentence tokens used in the pretest, 52 different sentence tokens that showed maximal perceptual ambiguity were selected. These were items with mean ratings between 3.2 and 4.8, and an overall mean rating of 4.0. As noted before, participants in the pretest were told that a score of 4 should indicate that a token shows equal surface resemblance to the coronal and noncoronal alternatives provided (e.g., right and ripe). Each of the sentences were marked with an inaudible cue 100 ms after the release of the stop consonant. These cues were used to trigger the presentation of the lexical decision probes. In addition to these 52 sentences, an additional 290 distractor sentences of similar length, content, and grammatical structure were recorded by the same speaker using the same procedures. The experimental sentences used in Experiment 1 are listed in Appendix A.

The lexical decision probes consisted of 171 familiar monosyllabic words and 171 monosyllabic pronounceable nonwords. They were presented visually in uppercase and in 24-point Helvetica font. In experimental trials, lexical decision probes were either related or unrelated to the prime items in the associated sentence. For example, if the prime item was the word right presented in a context meant to induce labialization of the final segment (e.g., This time she tried to get the right berries for her pie), the two potential related probes were the coronal alternative RIGHT and the noncoronal alternative RIPE. Unrelated prime items were created by pairing the same probes with other semantically and phonologically unrelated experimental primes. Therefore, RIGHT and RIPE could have served as unrelated probes following, for example, an assimilated token of the prime word hen, and HEM and HEN could have served as unrelated probes following the same token of right.

Procedure. Participants were tested individually in a sound-attenuated chamber. They wore Sony MDR-V6 headphones and were seated at a desk with a 17-in. Apple Multiscan 720 computer monitor and a PsyScope button box. Stimulus presentation, randomization, and data collection were performed using PsyScope graphic interactive environment software for designing psychology experiments (Cohen, MacWhinney, Flatt, & Provost, 1993). Participants were instructed to perform two tasks. For the first task, they were instructed to listen carefully to each sentence they heard in preparation for a comprehension test at the end of the session, and for the second, to determine whether the visual stimuli they saw were words or nonwords and to signal their judgment as quickly as possible by pressing one of two response keys. Participants were also informed that they could earn a monetary performance bonus by maintaining an accuracy level above 90% and a mean response time below 1 s on the lexical decision task and by correctly answering four out of five comprehension questions at the end of the testing session. They were instructed to place one finger from their dominant hand over each of two response keys at all times to speed their response times. Participants initiated each trial by pressing one of the keys. After a pause of 500 ms, the auditory stimulus containing the prime word was presented via the headphones. A lexical decision probe was presented on the computer monitor 100 ms after the offset of the prime word, for 500 ms while the auditory stimulus continued. If participants failed to make a lexical decision response within 1,400 ms of the onset of the probe item, they heard a 200-ms warning tone. After the first trial, all trials were initiated automatically by the computer, with a 2-s pause after the last keypress. At the completion of the on-line task, participants performed a five-item, forced-choice sentence completion task based on filler sentences they heard during the experiment.

Design. There were four experimental conditions formed by crossing two levels of relatedness between prime and probe items (phonologically related and unrelated) and two levels of underlying probe type (coronal and noncoronal). The experiment used a between-subjects design in which all participants heard the same prime stimuli and responded to the same probe stimuli, with different conditions formed by recombining specific prime and probe items in individual trials. No stimulus was presented more than once during a testing session. All participants contributed an equal number of trials to each of the four conditions. In addition to the 52 experimental trials, each participant completed 290 distractor trials. The first 10 trials used in each testing session were distractor trials designed to allow participants to acclimate to the task. Overall, each testing session included an equal number of word and nonword lexical decision probes. After the
Results

Responses with reaction times of less than 250 ms or greater than 1,200 ms were replaced with cell means to minimize the impact of anticipatory and strategic responding. This eliminated 5% of the data. Table 1 shows the mean response times and accuracy rates in each of the four experimental conditions after this preparation. There were no significant differences between conditions in accuracy rates. There was a significant main effect in reaction times for phonological relatedness in participant analyses and a marginal effect in item analyses, $F_1(1, 27) = 4.7, p < .05$, and $F_2(1, 51) = 3.5, p = .06$, with participants showing faster lexical decision responses for probes when they were phonologically related to preceding primes. A similar pattern held for probe type with underlying noncoronal probes producing faster responses than underlyingly coronal probes, $F_1(1, 27) = 3.9, p < .05$, and $F_2(1, 51) = 2.4, p > .05$. There were no significant interactions between relatedness and probe type, $F_1(1, 27) = 1.7, p > .05$, and $F_2(1, 51) = 1.3, p > .05$. Despite the lack of significant interaction effects, preplanned contrast analyses revealed significant priming by underlyingly coronal primes for coronal probes, $t_1(27) = 9.7, p < .001$, and $t_2(51) = 2.0, p < .05$, but not for noncoronal probes, $t_1(27) = 0.2, p > .05$, and $t_2(51) = 0.4, p > .05$.

Discussion

The results of Experiment 1 suggest that assimilation that creates perceptual ambiguity on-line. Participants hearing an assimilated token of the word *right* that perceptually approximated both *right* and *ripe* selectively accessed *right* but not *ripe*.

This finding is not consistent with the predictions that current models make about how human listeners deal with systematic phonological variation in spoken word recognition. For example, Lahiri’s (Lahiri, 1998; Lahiri & Marslen-Wilson, 1991) underspecification model predicts that listeners should simultaneously access both *right* and *ripe*, because the underspecified representations of these items would not mismatch an assimilated token of [jʌlp]. Gaskell’s (Gaskell & Marslen-Wilson, 1996, 1998) inferential model similarly predicts that listeners should access both words, because assimilation of labial place by a coronal segment was valid in the context of the following labial segment in the experimental sentences. Instead, the priming results show that the listener accessed only the intended word.

These results might be interpreted in two ways. One interpretation is that assimilation produces incomplete or noncategorical change in the acoustic cues to place features, leaving the listener with sufficient information to determine the nonassimilated value of the place feature. The tokens used in this experiment, judged to be ambiguous in surface form in the off-line perceptual rating task, might have been especially likely to show incomplete change in the acoustic cues to place features. However, according to this interpretation, even strong assimilation may create an amalgam of underlying and assimilated features that listeners could have used to recover both feature values simultaneously. Such a mechanism would have the advantage of resolving ambiguity during access, thus avoiding the need for postlexical selection mechanisms.

The other interpretation is that the degree of feature change was overestimated by the off-line perceptual rating task. If this was the case, the stimuli could have actually shown relatively weak assimilation that was insufficient in creating discrete feature change or on-line lexical ambiguity. Weakly assimilated tokens may have provided listeners with strong coronal place information and little or no conflicting noncoronal place information. Under these conditions, one would also not expect activation of noncoronal interpretations (e.g., *ripe*). Experiment 2 addressed this concern by replicating Experiment 1, using only the most strongly assimilated items as measured by the perceptual rating task and verified by acoustic analyses.

Experiment 2

Experiment 2 replicated Experiment 1 using strongly modified primes. This provided a strong test of the hypothesis that English place assimilation provides usable acoustic information about the underlying place of articulation. If even the most extreme assimilation preserved underlying place information that listeners could use, then participants should have shown priming of the coronal interpretation of the prime (e.g., *right*) but not of the apparent surface noncoronal interpretation (e.g., *ripe*). This experiment also addressed the concern that the perceptual rating task overestimated the degree of modification of the stimuli and that those stimuli were only weakly modified. If priming of the coronal form in Experiment 1 merely reflected the survival of acoustic cues to the coronal place of articulation despite some assimilation, then priming in Experiment 2 should have reflected the activation of the putative noncoronal form of the strongly assimilated prime items (e.g., *ripe*).

Method

Participants. Thirty-six participants were drawn from the same population as in Experiment 1. None had participated in the previous experiment. These included 24 men and 12 women ranging in age from 18–45 years, with a mean age of 24.0 years. They were selected using the same criteria and were paid the same rate as participants in the first experiment.

Stimuli. The experimental stimuli were 52 items constructed using the same criteria as those in Experiment 1, with perceived degree of modification determined through the same pretesting results. The 52 items that were rated as most resembling the noncoronal interpretation of the stimuli were selected for inclusion. All items had individual mean ratings between

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<tr>
<th>Probe type</th>
<th>Related prime</th>
<th>Unrelated prime</th>
<th>Priming effect</th>
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<tr>
<td>Noncoronal RT</td>
<td>682</td>
<td>689</td>
<td>7</td>
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<tr>
<td>Accuracy rate</td>
<td>.96</td>
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<tr>
<td>Coronal RT</td>
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<tr>
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<td>.94</td>
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Note. Noncoronal probe type = surface correspondence with the prime; coronal probe type = underlying correspondence with the prime.
4.2 and 6.8, with an overall mean rating of 5.2 on a 7-point scale, for which a score of 0 indicated that an item was unambiguously coronal (e.g., right), and a score of 7 indicated that an item was unambiguously noncoronal (e.g., ripe). These items were all among the 10% of tokens showing the highest mean rated degree of assimilation.

Acoustic analyses of stimuli. Given the concern that the off-line ratings task may have underestimated the degree of modification of prime items used in the first experiment, I performed acoustic analyses on the stimuli used in Experiment 2 to provide converging evidence of modification. Because the resonances of the vocal tract change as it moves to create a consonant closure, and closures produced at different points in the vocal tract produce different characteristic changes in these resonances or formants, the acoustic consequences of place of articulation can be measured quantitatively by tracking formant transitions between a vowel and the closure associated with a word-final consonant. Given the complex acoustic and articulatory effects of nasal consonants on immediately preceding vowels (Stevens, 1998), analyses were limited to items ending in oral consonants.

For purposes of acoustic comparison, I needed tokens of both unmodified coronals and noncoronals (right and ripe). To this end, I recorded two additional versions of each of the 52 experimental sentences from Experiment 2, spoken by the same speaker and recorded using the same equipment and procedures that were used to record all auditory stimuli reported in this article. In one version, the item ending in the coronal segment was replaced with a corresponding item ending in a noncoronal segment. For example, the word right could have been replaced by the word ripe. In another version of the sentence, the item ending in the coronal segment was immediately followed by a word beginning with a coronal segment. For example, the phrase right berries could have been replaced by the phrase right dairy. This context would produce an unmodified version of the final coronal segment in right. Given these three versions of the sentence (coronal in nonmodifying context, underlyingly coronal in modifying context, and noncoronal), modification could be measured by comparing the modified coronal with both the unmodified coronal and the noncoronal. All three versions of each sentence were digitized and acoustic analyses were performed using unpublished software developed at the Research Laboratory of Electronics at MIT, based on the work of Dennis Klatt. Prior to making these acoustic analyses, two listeners compared the underlyingly coronal and noncoronal tokens in each triplet to assure that they constituted true minimal pairs in the speaker’s dialect. Formant peaks were identified for the second formant (F2) and the third formant (F3) at two locations in each stimulus. The first location was the time of the vocalic pitch period showing the greatest amplitude. This location usually corresponded roughly with the middle of the vowel. The second measurement location was the penultimate pitch period showing a distinct F3 prior to the consonant closure. Formant transitions were calculated by subtracting the second measure from the first measure for each token. Separate analyses were performed for F2 and F3.

The results of these analyses are shown in Figure 1. In all analyses, mean formant change measures for modified coronal segments fell between measures for unmodified coronal segments and underlyingly noncoronal segments. Contrast analyses were performed, in which I examined labial and velar assimilation separately. These analyses revealed no significant differences between modified coronals and noncoronals. However, they did reveal significant differences in F2 change between unmodified coronals and coronals assimilated to labials, \( t(37) = 3.0, p < .005 \), as well as marginally significant differences in F3 change between unmodified coronals and coronals assimilated to velars, \( t(65) = 1.7, p < .10 \). I performed an additional series of contrast analyses, collapsing across labial and velar assimilation conditions to increase the power of the design. For the purposes of these comparisons, I normalized values associated with assimilated coronal and unmodified coronal segments for the direction of change for labial and velar environments. Analyses of the mean F2 and F3 change measures showed that assimilated coronals had values intermediate between coronal and noncoronal counterparts. Therefore, I normalized measures for underlying noncoronals and coronals that had undergone velar or labial assimilation, by adding their absolute deviation from the analogous coronal item to the value associated with that item. These measures accordingly reflected the degree of change in acoustic measures rather than the direction of that change. Contrast analyses performed on these derived measures revealed significant differences in F2 change between both unmodified and modified coronals, \( t(78) = 2.4, p < .05 \), and between modified coronals and unmodified noncoronals, \( t(78) = 2.5, p < .05 \). Analyses of F3 change showed marginally significant differences between unmodified and modified coronals, \( t(78) = 1.9, p = .06 \), but no difference between modified coronals and unmodified noncoronals, \( t(78) = .3, p > .05 \). This broad pattern of results, with assimilated coronals patterning with unmodified coronals in some acoustic measures, noncoronals in other measures, and distinctly from both coronals and noncoronals in others, is consistent with those shown by 6 other naive talkers in a study by Gow and Hussami (1999) using similar minimal triplets. This suggests
that my stimuli are representative of place-assimilated coronals produced by other English speakers.

Recognizing the limitations of a design with a relatively small number of observations and the inability to control for potentially significant factors like vocalic context, these results appear to buttress the results of the perceptual pretest in showing that the stimuli are strongly modified.

Procedure and design. The design and procedure used in Experiment 2 were exactly the same as those used in Experiment 1.

Results

Outliers were replaced with cell means using the same criteria and methods that were used in the preparation of the data from Experiment 1. Table 2 shows the mean response and accuracy rates for each of the four experimental conditions. Participants had an overall accuracy rate of 95% with no significant differences in error rates between conditions. Analysis of reaction time data showed a significant effect for phonological relatedness, with faster responses to related probes than to unrelated ones, $F_{1}(1,35) = 6.8, p < .01,$ and $F_{2}(1,51) = 4.8, p < .05.$ There was no significant main effect for underlying probe type, $F_{1}(1,35) = 1.8, p > .05,$ and $F_{2}(1,51) = 0.05, p > .05.$ There was also a partially significant interaction between probe type and relatedness, $F_{1}(1,35) = 6.2, p < .05,$ and $F_{2}(1,51) = 2.0, p > .05.$ Two planned comparisons directly examined the pattern of priming underlying this interaction. These revealed significant priming of the coronal probe, $t_{1}(35) = 5.8, p < .001,$ and $t_{2}(51) = 11.6, p < .001,$ but not of the noncoronal probe, $t_{1}(35) = 0.2, p > .05,$ and $t_{2}(51) = 0.3, p > .05.$

Discussion

The results of Experiment 2 closely replicate those of Experiment 1. Participants showed priming of the underlying coronal interpretation of prime items, but not of their apparent surface noncoronal interpretation. This pattern of selective activation is once again inconsistent with the predictions of both underspecification and inferential accounts of processing. It also supports the hypothesis that spontaneous assimilation provides recoverable acoustic evidence about the underlying form of modified items, even for tokens that were judged to be strongly assimilated in the off-line perceptual rating task.

These results, because they were produced with highly selected prime items that show strong perceptual and acoustic evidence of robust modification, suggest that the results of Experiment 1 are not merely attributable to weak modification of the primes used in that experiment. Perceptual pretesting showed that all primes were perceptually rated to be more noncoronal than coronal. These items were rated within the top decile of perceived noncoronality among assimilated items. Supported by acoustic analyses showing significant differences between these items and unmodified coronals, at least one measured difference between them and unmodified noncoronals, and because the speaker was selected for his strong assimilation (as judged by informal listening), it appears that the prime items represented the most strongly modified end of the assimilation continuum. Although this occurred, these items were perceptually and acoustically distinct from underlying noncoronals. This is consistent with articulatory evidence from Nolan (1992). The results of Experiment 2 show that strong assimilation does not lead to the misidentification of words or lexical ambiguity. The implication of this is that assimilation preserves usable acoustic–phonetic evidence about the unmodified form of modified items.

There is another potential interpretation of these data. The stimuli for these experiments were constructed entirely to meet phonological and acoustic–phonetic specifications. However, participants had access to other forms of information as well. The use of real words introduces the possibility that results reflected underlying lexical biases. Furthermore, the use of sentential contexts raises the possibility that higher order constraints, including those imposed by semantic, pragmatic, and syntactic context, may have systematically biased the participants toward a particular interpretation of the stimuli. It is therefore a possibility, although unlikely, that these factors systematically biased participants toward the coronal interpretation for enough of the prime items to influence the results. To explore this hypothesis, in Experiment 3 I examined the effects of changing the acoustic form of the prime stimuli while holding lexical and contextual factors constant.

Experiment 3

The purpose of Experiment 3 was to determine whether the results of Experiments 1 and 2 were attributable to the recovery of residual acoustic evidence of the underlying place of articulation of modified segments or attributable to uncontrolled, systematic, contextual, and lexical biases that promoted the coronal interpretation of prime items over their noncoronal interpretations. Experiment 3 replicated Experiment 2 with one difference. The experimental stimuli in this experiment were rerecorded using a reader’s script that replaced coronal primes (e.g., right) with their noncoronal counterparts (e.g., ripe; see Appendix B). In all cases, this substitution preserved the lexical and contextual constraints that were in the prior experiment and produced well-formed sentences. This manipulation was intended to create prime items ending in acoustically unambiguous noncoronals. If the acoustic account of the results of the previous experiments was correct, these items should have produced the opposite pattern of results: priming for noncoronal lexical decision probes (e.g., RIPE), but not for coronal probes (e.g., RIGHT). On the other hand, if the results of Experiment 2 were attributable to lexical or contextual bias in the construction of the prime materials, Experiment 3 should have shown the same pattern of priming for coronal probes (e.g., RIGHT), but not for noncoronal ones (e.g., RIPE).

Table 2

<table>
<thead>
<tr>
<th>Probe type</th>
<th>Related prime</th>
<th>Unrelated prime</th>
<th>Priming effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Noncoronal</td>
<td>RT 711</td>
<td>718</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Accuracy rate</td>
<td>.96</td>
<td>.94</td>
</tr>
<tr>
<td>Coronal</td>
<td>RT 699</td>
<td>729</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>Accuracy rate</td>
<td>.97</td>
<td>.95</td>
</tr>
</tbody>
</table>

Note. Noncoronal probe type = surface correspondence with the prime; coronal probe type = underlying correspondence with the prime.
**Method**

Participants. The participants were 32 members of the MIT community, including 12 women and 20 men, between the ages of 18 and 50 years, with a mean age of 24.7 years. The same inclusion criteria were used and participants were paid at the same rate as in the previous experiments.

Stimuli, procedure, and design. Experiment 2 closely modeled Experiment 1, the only difference was that experimental priming words with assimilated, underlying coronal offsets were replaced with items with unmodified noncoronal place. For example, if Experiment 2 included the prime stimulus right in the carrier sentence This time she tried to get the right berries for her pie, Experiment 3 included an identical carrier sentence in which the word right was replaced by the word ripe on the reader's script. All 52 experimental condition stimuli used in Experiment 2 were replaced in this manner. All stimuli were recorded by the speaker who produced the stimuli for the previous experiments. The stimuli used in this experiment served as the unmodified noncoronal items in the acoustic analyses of the stimuli used in Experiment 2. The same lexical decision probes were used in both this experiment and Experiment 2, forming the same four experimental conditions by crossing two levels of phonological relatedness with two levels of probe-item, final-segment coronality. The same distractor sentences and lexical decision probes were used in all experiments reported in this article.

**Results**

The data were prepared using the same methods that were used in the two previous experiments. Mean reaction times and accuracy rates for the four experimental conditions are shown in Table 3. Reaction time analyses revealed a significant main effect for probe type, $F(1, 31) = 8.9, p < .005$, and $F_2(1, 51) = 8.1, p < .005$, with responses to noncoronal lexical decision probes (e.g., RIPE) faster than those to coronal probes (e.g., RIGHT). There was no effect for phonological relatedness, $F_1(1, 31) = 0.0, p > .05$, and $F_2(1, 51) = 0.1, p > .05$. The interaction between relatedness and probe type was significant, $F_1(1, 31) = 9.9, p < .005$, and $F_2(1, 51) = 4.9, p < .05$. Planned contrast analyses showed significant priming of noncoronal lexical decision probes by noncoronal primes, $t_1(31) = 5.2, p < .001$, and $t_2(51) = 4.5, p < .001$. There was also significant negative priming of coronal probes by the noncoronal primes, $t_1(31) = 4.2, p < .001$, and $t_2(51) = 4.0, p < .001$. Analysis of the accuracy data confirmed a partially significant main effect for probe type, $F_1(1, 31) = 4.8, p < .05$, and $F_2(1, 51) = 2.5, p > .05$, showing more accurate lexical decisions for noncoronal primes than for coronal ones. There were no other significant main effects, interactions, or contrasts involving accuracy results.

**Table 3**

<table>
<thead>
<tr>
<th>Probe type</th>
<th>Related prime</th>
<th>Unrelated prime</th>
<th>Priming effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Noncoronal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RT</td>
<td>681</td>
<td>702</td>
<td>21</td>
</tr>
<tr>
<td>Accuracy rate</td>
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<td>.95</td>
<td>-.01</td>
</tr>
<tr>
<td>Coronal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RT</td>
<td>731</td>
<td>702</td>
<td>-29</td>
</tr>
<tr>
<td>Accuracy rate</td>
<td>.93</td>
<td>.93</td>
<td>0</td>
</tr>
</tbody>
</table>

Note. Noncoronal probe type = identity with the prime; coronal probe type = potential underlying correspondence with the prime.

**Discussion**

The results of Experiment 3 show a pattern of priming of noncoronal probes (e.g., RIPE), but not coronal probes (e.g., RIGHT), by underlyingly noncoronal primes (e.g., ripe) presented in the same contexts as those used in Experiment 2. This pattern of results is a mirror opposite of the results found in Experiments 1 and 2. As such, it is incompatible with the view that the results of Experiment 2 are attributable to systematic nonacoustic biases in the priming stimuli, given the assumption that the same biases should produce the same pattern of results. Once again, participants appeared to be able to discriminate the underlying form of prime items. This ability is inconsistent with the characterization of assimilation as producing full feature change. If assimilation did produce such change, the priming stimuli used in Experiment 3 would have been lexically ambiguous, and participants might have been expected to show activation of both coronal and noncoronal interpretations of the prime. From the perspective of underspecification theory, an item such as the word right is entirely consistent with the word /alp/ because the place of the final segment is unspecified. From the perspective of inferential accounts of assimilation, because the word ripe is followed by the labial segment at the onset of the word berries, there is a valid phonological context for the assimilation of the final segment in right to produce the surface form /alp/, with full assimilation to the labial place of articulation, so right should be accessed. These results are therefore inconsistent with both the underspecification and inferential accounts of processing and with the hypothesis that the results of Experiment 2 are attributable to systematic bias in the stimulus materials.

Because listeners discriminate between modified and unmodified forms on the basis of acoustic information, it seems assimilation does not create lexical ambiguity. The results of the acoustic analyses of the stimuli used in Experiments 2 and 3 reveal one potential source of disambiguation. F2 transitions in modified coronal primes used in Experiment 2 (e.g., the naturally assimilated form of right in right berries) were significantly different from those in analogous noncoronal primes used in Experiment 3 (e.g., the underlyingly labial /p/ in ripe berries). The combination of this acoustic difference and the contrasting results in the two experiments suggests that assimilatory modification preserves evidence of underlying feature values and that listeners exploit this evidence in spoken word recognition.

The results of the first three experiments suggest that listeners are able to access the underlying form of words despite potential lexical ambiguity introduced by the phenomenon of regressive place assimilation. Experiment 4 addressed the question of how listeners resolve this apparent ambiguity. English coronal place assimilation is essentially a context effect. One way to approach the problem of how listeners understand assimilated speech is by analogy to general solutions that have been proposed for resolving the problem of context effects in speech perception. Below, I outline four potential solutions and suggest that they are empirically discriminable on the basis of the role that they ascribe to context.

The simplest account argues that assimilation does not create ambiguity in the first place. Stevens and Blumstein (1978, 1981) showed that spectral characteristics of stop consonant releases may provide context-invariant cues to place values. In principle, such a
cues might encode the underlying place of articulation of even strongly modified coronals. Given invariant cues to underlying place, listeners would not need to rely on postassimilation context to disambiguate the underlying place of such segments.

The second possibility is that listeners use postassimilation context to infer the underlying place of assimilated segments. Gaskell and Marslen-Wilson (1998) presented a strong version of this mechanism in which postassimilation context may lead a listener to identify a segment that is perceptually and unambiguously noncoronal as an underlying coronal. I have argued (Gow, 2001) that this view is not viable because it fails to address the role played by acoustic factors in the first three experiments. However, Mann and Repp (1980) provided a model of phonological inference based on consideration of articulatory dynamics that might address the role of these subtle acoustic factors. They argue that listeners compensate for coarticulation in speech perception by using phonological context to adjust their criteria for interpreting phonetic feature cues. For example, speakers round their lips when they produce the vowel /u/. This lowers the frequency of the first spectral peak of a preceding fricative. The production of the vowel /u/ does not have this effect. Significantly, listeners use this peak to discriminate between [J] and [s]. Rounding-related lowering could make [s] take on the spectral properties of [J]. However, Mann and Repp demonstrated that listeners show a shift in the perceptual boundary between [s] and [J] when the fricative is followed by [u] instead of an [a]. In the case of coronal place assimilation, listeners might adjust their mapping criteria when a segment with ambiguous place is followed by a noncoronal. Such an adjustment would have to be robust enough to allow for the recognition of underlying form in Experiments 1 and 2 and yet small enough to avoid misclassifying the unambiguous noncoronal primes in Experiment 3 as coronals.

A third possibility is that listeners use linguistic or articulatory knowledge to infer the underlying form of assimilated segments. A number of theorists have suggested that speech perception is constrained by knowledge of speech production. Several related accounts of speech perception that focus on the role of articulation in perception argue that listeners recognize speech through a series of mappings that trace the speech chain backward from perception through production to the speaker’s initial intent (Halle & Stevens, 1962; Liberman, Cooper, Shankweiler, & Studdert-Kennedy, 1967; Mann & Repp, 1980).

Brownman and Goldstein (1990) argued that assimilation reflects the overlap between two adjacent gestures. Soon after speakers begin to produce a coronal gesture for one segment they may begin a labial gesture associated with a subsequent segment. Listeners may resolve the perceptual ambiguity this creates by recovering and factoring apart the two articulatory gestures. Fowler and Smith (1986) hypothesized that if listeners are able to factor apart overlapping gestures, context should not affect the perception of segments whose acoustic realization is influenced by another segment. The only conceivable role of postassimilation context within this account is one that facilitates the factoring of overlapping gestures. However, evidence from a variety of studies using gating and cross-splicing techniques demonstrates that listeners are able to anticipate subsequent context in instances of regressive assimilation and anticipatory coarticulation without exposure to such context (Gow, 2001; Kuehn & Moll, 1972; Lahiri & Marslen-Wilson, 1991; LaRiviere, Winitz, & Herriman, 1975; Lehiste & Shockey, 1972; Mann & Repp, 1981; Martin & Bunnell, 1981; Ostreicher & Sharf, 1976; Yeni-Komshian & Soli, 1981). If listeners recognize assimilated speech by factoring overlapping gestures apart, they can clearly do so without access to postassimilation context. This suggests that the kind of articulatory inference described by Fowler and Smith (1986) does not depend on postassimilation context.

A parallel inference might be made based on knowledge of one’s phonological system. In English phonology, a coronal segment can undergo labial assimilation, but a labial segment cannot undergo coronal assimilation. Thus, a listener hearing simultaneous evidence of coronality and labiality could infer that it is the result of regressive labial assimilation of a coronal segment. In the case of articulatory inference, context does not appear to be necessary to make this inference.

The last account reflects the process of feature parsing, which is the aligning of feature cues extracted from the speech stream with abstract segment or position representations. Acoustic feature cues associated with a single segment may be temporally dispersed. For example, the place of articulation of an initial stop consonant may be encoded in the spectrum of the stop release as well as in the formant pattern at a subsequent vowel that follows the release. Furthermore, features cues associated with neighboring segments may show overlapping temporal distributions. For example, the nasality of a postvocalic consonant is marked by lowering of F1 during the preceding vowel. For listeners to combine features and derive higher order representations such as segments, they must determine which features are part of which segmental positions. In the case of assimilation, listeners recovering contemporaneous evidence for two places of articulation may disambiguate items by associating one place value with the modified segment and the other place value with the subsequent segment. Several studies have shown that listeners may use perceived assimilation to anticipate subsequent feature values (Gow, 2001; Lahiri & Marslen-Wilson, 1991). For example, a listener hearing a token of the word green, in which the final /n/ assimilates labial place, appears to anticipate that the next item will begin with a labial segment. This anticipation could be interpreted as mapping between evidence for labiality in the speech stream and the segmental position following the assimilated segment.

When anticipation is viewed as the alignment of a feature value with a subsequent segmental position, the alignment process itself can play a role in disambiguation. Consider the right berries example. Ambiguity stems from the combination of coronal and labial features by the final segment in the first word. If the labiality of this segment is associated with the labiality of the [b] in berries, there is no ambiguity. Drawing the labiality away leaves only evidence of coronality to align with the final segment. This would lead to the activation of right but not ripe. Given this approach, removing postassimilation context should have led to ambiguity. If there is nothing to draw away the labiality, lexical activation should have reflected the coexistence of weak coronal activation and weak labial activation. Listeners should have accessed both right and ripe.

I conducted a fourth experiment to distinguish between these accounts; each makes a specific prediction about how the recognition of assimilated word forms would be affected by the loss of postassimilation context. Experiment 4 was a modified replication of Experiment 2. Once again, form priming was used to probe the
pattern of lexical access that listeners show after hearing highly assimilated tokens. However, in Experiment 4, the context that drove the assimilation was removed. If underlying form is marked by invariant acoustic cues, context should have had no effect on recognition, and the results of Experiment 4 should have been the same as those of Experiment 2. Listeners should have accessed only the coronal interpretation of prime items (e.g., right, but not ripe). If listeners use postassimilation context to adjust their perceptual categories, removing context should have blocked adjustment. In this case, listeners should have accessed the apparent noncoronal item (e.g., ripe), but not its underlying coronal form (e.g., right). If listeners rely on articulatory or phonological knowledge to infer the underlying form of segments that manifest hybrid place information, context should not have affected processing and listeners should have shown priming of the coronal form (right), but not the noncoronal form (ripe). Finally, if listeners disambiguate assimilated forms by assigning coronality to one segment and noncoronality to the next, the loss of context should have created lexical ambiguity. Listeners would have had to associate both feature values with the same segment. They should have used evidence of coronality to access right and evidence of noncoronality to simultaneously access ripe.

Experiment 4

Method

Participants. Thirty-six participants were drawn from the MIT community. They included 11 men and 25 women with a mean age of 21.6 years. The inclusion criteria and system of compensation were the same as those used in the previous three experiments.

Stimuli, procedure, and design. Experiment 4 used the same stimulus materials and experimental conditions as Experiment 2. The only modification was that the auditory stimuli were gated in Experiment 4 to end 100 ms prior to the onset of the presentation of the lexical decision probe. For example, if the prime in Experiment 2 was a strongly modified token of the word right in the sentence This time she tried to get the right berries for her pie, the analogous stimulus in Experiment 4 was the same stimulus token gated after the word right, leaving the sentence fragment This time she tried to use the right //. All gating was performed at ascending zero crossings. In the experimental trials, all edits were made just prior to the consonantal release of the segment following the closure associated with the place-assimilating segment. The consonantal release was replaced with a low-amplitude, 10-ms pulse of noise. This noise pulse was inserted to suggest a consonantal release without providing spectral information about the place of articulation of the putative consonant. In the distractor trials, all gates appeared within words. The insertion of the noise pulse in experimental trials and the use of intraword gating in distractor trials was done to make it clear to participants that the acoustic stimuli were derived from complete sentences, and to induce the expectation that some unknown context followed the gated sentence fragment. This was important because assimilation occurs only in the presence of postcoronal context. Gating position was varied across distractor items to minimize expectation. Beyond these modifications, the design and procedures used in this experiment matched those used in Experiment 2.

Results

The data were prepared using the same procedures that were used in the previous experiments. Table 4 summarizes the accuracy and reaction time data. Analyses of the reaction time data revealed a main effect for relatedness, with participants responding faster to lexical decision probes that were related to prime items than to ones that were unrelated to the primes, $F(1, 35) = 17.6$, $p < .001$, and $F(1, 51) = 13.2, p < .001$. There was no effect for probe type, $F(1, 35) = 0.1, p > .05$, and $F(1, 51) = 0.1, p < .05$, and no interaction between relatedness and probe type, $F(1, 35) = 0.4, p > .05$, and $F(1, 51) = 0.5, p > .05$. Planned contrasts showed that gated assimilated primes such as right [1aIp] prime both coronal (e.g., RIGHT), $t(35) = 9.0, p < .001$, and $t(51) = 9.0, p < .001$, and noncoronal (e.g., RIPE) probes, $t(35) = 5.6, p < .001$, and $t(51) = 4.4, p < .001$. Although the accuracy data showed a similar pattern, there were no significant main effects, interactions, or preplanned contrast results in a complete set of analyses paralleling the reaction time analyses.

Discussion

The purpose of Experiment 4 was to determine how listeners recognize the underlying form of potentially lexically ambiguous items. Participants showed priming for both coronal and noncoronal interpretations of assimilated coronals (e.g., the segment approximating [p] in labialized tokens of right) when postassimilation context was removed. Because the same stimulus tokens produced selective priming for their noncoronal interpretations in Experiment 2 when presented with postassimilation context intact, it appears that context plays a role in the disambiguation process.

The results of Experiment 4 are consistent with the predictions of the feature parsing hypothesis. According to this hypothesis, listeners recover evidence of the underlying correspondence with the prime. The assimilated segment and noncoronality of the subsequent segment and disambiguates by associating the correct feature with the correct segment. The final segment of the first word in right berries combines the coronality of the /b/ in right and the labiality of the /b/ in berries. In Experiment 2, evidence for the labiality of this segment was associated with evidence for the labiality of /b/ in berries. With evidence of labiality drawn away in this manner, listeners were left with a simple mapping between recovered evidence of coronality and the last segment in right. In Experiment 4, there was no postassimilation labial to draw away evidence of labiality, and therefore listeners simultaneously mapped evidence of coronality to the final segment (accessing right) and evidence of labiality to the same position (accessing ripe).

The contrast between the results of Experiments 2 and 4 is inconsistent with the claim that listeners use contextually invariant cues to identify the place of assimilated coronals. If such cues were
present, the loss of context should have had no effect on their
terpretation, and the results of Experiment 4 should have duplicat-
ted those of Experiment 2. Stevens and Blumstein (1978, 1981)
have identified spectral characteristics of stop releases that serve as
invariant cues to place of articulation. However, when two stop
consonants abut one another in connected speech as they do in
these stimuli, the first stop is frequently unreleased (Stevens,
1998). A review of the stimuli revealed that none showed identifi-
able acoustic evidence of release, and therefore context-invariant
place cues may have been unavailable to listeners. Furthermore,
there was no available evidence bearing on the question of whether
cues remained invariant when there was strong place assimilation.

These findings are also inconsistent with the predictions of
accounts using regressive phonological inference. Claims for re-
gressive inference in the processing of assimilated speech rest on
a series of demonstrations of context effects (Gaskell & Marslen-
compensation for coarticulation suggested that listeners shift their
perceptual categories for interpreting feature cues on the basis of
postsegmental context. If such a mechanism could apply to assim-
ilation, listeners might use postassimilation context to modulate
their interpretation of assimilated place cues and recover underly-
ing place. Pretesting revealed that the stimuli used in Experiments
2 and 4 resembled noncoronals more than coronals. If listeners
make regressive phonological inferences, postassimilation context
might have caused listeners to rescale their perceptual criteria in
Experiment 2 and recognize these stimuli as underlyingly coronal.
However, the absence of postassimilation context in Experiment 4
should have left listeners with no basis for adjusting these catego-
ries, and so they should have been treated as noncoronals. The
results show that this was not the case.

Finally, the results of Experiment 4 are incompatible with the
two knowledge-driven accounts of assimilated speech perception.
Fowler and Smith (1986) suggested that listeners resolve context
effects by factoring apart overlapping gestures. Context could play a
role in this process if it were required to recover the gesture
associated with the segment that assimilates the coronal. However,
listeners who hear assimilated items gated at their offsets success-
fully anticipate subsequent context (Lahiri & Marslen-Wilson,
1991), suggesting that the portion of the gesture heard during the
assimilated segment is sufficient. Factoring does not depend on
postassimilation context, and so the factoring account cannot ex-
plain why removing context affected lexical activation. It is also
inconsistent with the view that listeners use knowledge of their
phonological systems to infer that the co-occurrence of labiality
and coronality in a single segment reflects the regressive labial
assemblage of a coronal segment. This inference does not rely on
knowledge of actual postassimilation context. Knowledge-driven
accounts of the perception of assimilated speech predict that lis-
teners should have interpreted assimilated segments the same way
whether or not context was present. The divergent results of
Experiments 2 and 4 show that this was not the case.

General Discussion

The purpose of this research was to determine whether English
place assimilation can create lexical ambiguity. The results of the
first three experiments presented in this article suggest that it does
not create ambiguity under normal conditions. In each experiment,
participants showed selective priming of the item that the speaker
had intended to produce, despite potential ambiguity in the map-
ping between its surface and underlying forms. In Experiments 1
and 2, participants showed priming for coronal probes (e.g.,
RIGHT), but not for noncoronal probes (e.g., RIPE), following the
presentation of spontaneously assimilated, underlyingly coronal
primes (e.g., right). This seems to be a surprising result, because the
surface form of these primes was judged, in perceptual pre-
testing, to show equal resemblance to both probes in Experiment 1
and greater resemblance the noncoronal item in Experiment 2. This
appears to violate the commonsense tenet that listeners access the
lexical candidate that most closely resembles input.

This might be interpreted as evidence against simple activation-
based models of word recognition in which the degree of lexical
activation reflects the degree of correspondence between the per-
ceptual specifications derived from the input and the stored spec-
ification of lexical representations (Marslen-Wilson, 1987; Mc-
Clelland & Elman, 1986; Norris, 1994; Norris et al., 1995).
Furthermore, it counters the predictions of both underspecification
and inferential accounts of how listeners cope with assimilatory
modification (Gaskell & Marslen-Wilson, 1996, 1998; Lahiri
& Marslen-Wilson, 1991). If assimilation truly produced surface
forms with equally viable mappings, with multiple underlying
forms, then nonheuristic activation mechanisms should activate all
viable underlying forms; apparently, they do not.

The observation that the acoustic signal provides sufficient
information to disambiguate the underlying form of a word sug-
gests that a simple activation-based model might account for the
recognition of modified words, given an enriched understanding of
the nature of the signal or of the mapping between acoustic feature
cues and the lexicon. Although researchers may recognize that
assimilation can involve varying degrees of modification, this
recognition has not been captured in recognition models. Instead,
they focus on the need for specialized representations or processes
for coping with assimilation, with the assumption that more par-
simonious feature matching approaches are ill-suited to deal with
this modification, because the place feature is fully assimilated.
However, this assumption appears to be false.

Whereas other forms of systematic, phonetic modification may
potentially destroy the acoustic cues that specify the correspon-
dence between the recoverable features of a spoken word token
and its lexical representation, English place assimilation appar-
cently does not. Therefore, there is no strong motivation for positing
either underspecified representations or regressive inferential pro-
cesses to account for humans’ ability to recognize place-
assimilated tokens. Instead of destroying or eliminating cues to
features of an item’s underlying form, place assimilation appar-
cently provides sufficient acoustic information to directly access
this representation. Given that assimilation has served as the test
case for most published psycholinguistic research into the prob-
lem, the status of other phonological processes remains an open
empirical question. Manuel et al. (1992) found similar evidence of
preserved acoustic evidence of the underlying form of severely
reduced consonants and vowels, but little work has examined the
role of such residual information in the perception of words that
have undergone other processes, such as deletion, epenthesis,
mutilation, or other forms of neutralization. Should future work
reveal that such processes fail to preserve information about un-
derlying form, underspecified representations or inferential mech-
Characterizing Assimilation

The observation that listeners show selective activation of the intended underlying item in the first three experiments, and that this selectivity cannot be attributed to lexical or contextual biases, suggests that assimilation preserves acoustic evidence about the unmodified form of words. This might be interpreted in two ways. The simplest interpretation is that assimilation produces intracategorical modification. That is, a labialized coronal segment still falls within the acoustic and perceptual range of a coronal even if it may tend toward the labial end of this range. Although this may be an appropriate interpretation of the results of Experiment 1, which used priming stimuli that were judged to be perceptually ambiguous, it does not appear to be an appropriate interpretation of the results of Experiment 2. Acoustic analyses suggested that the underlyingly coronal stimuli used in this study were in some sense acoustically more similar to noncoronals than to coronals. More important, perceptual pretesting showed that listeners found these stimuli to sound more like noncoronals than coronals.

The results of Experiment 2 and perceptual pretesting create a paradox. How could a stimulus have been judged to sound noncoronal at the surface level in off-line tasks and still be implicitly treated as underlyingly coronal on-line tasks? Perceptual judgment tasks, such as the one used in pretesting, are used widely to examine featural and subfeatural acoustic modifications in speech research (Gaskell & Marslen-Wilson, 1998; Marslen-Wilson et al., 1995; Marslen-Wilson & Warren, 1994). Furthermore, Nolan (1992) found close correspondence between electropalatographic evidence of pure coronal versus modified coronal closure in assimilated speech on the one hand, and off-line perceptual judgments of place of articulation on the other, suggesting that off-line tasks provide a reliable measure of articulatory modification. This suggests that the perceptual task yields a valid measure of perceived surface place of articulation. At the same time, form priming is also widely validated as a measure of lexical activation (Zwitserlood, 1996).

There are two points to consider in thinking about the results of these tasks. The first is that form priming and the perceptual rating of surface form similarity address different things. The perceptual judgment task used in pretesting intentionally taps the surface form of items while ignoring their underlying forms. At the same time, form priming tasks address lexical activation, which presumably reflects underlying form and does not necessarily reflect perceived surface form. This is especially clear in the case of closely related stimuli, such as SERENE, despite phonological mismatch, whereas pseudoaffixed words, such as forty, failed to prime more phonologically similar words, such as fort. The second point is that it is not unusual to find a disjunction between the results of on-line versus off-line tasks. A number of authors have argued that these two types of tasks may reflect different aspects of word processing related to the time course of processing and/or the involvement of strategic processing (cf. Marslen-Wilson & Tyler, 1980; Onifer & Swinney, 1981). Together, these points suggest that the two tasks tap different levels of representation that may exist in parallel.

The solution to this paradox may lie in an alternative characterization of the perceptual consequences of assimilation. Listeners may perceive both the underlying form of a modified item and it being modified in a particular way. If this is the case, the priming results may have reflected access of underlying form, whereas the perceptual judgment results may have reflected an awareness of the modification. This view is buttressed by another series of experiments (Gow, 2001) that demonstrated listeners use the acoustic information in a token that has undergone assimilatory modification to anticipate the upcoming segment that drives the assimilation. In these experiments, Gow used phoneme monitoring and form priming to demonstrate that a listener, hearing a token of the word ten in which the final coronal segment had been labialized, anticipated that the next word began with a labial segment. For example, the phoneme monitoring experiment revealed that a word-initial noncoronal (e.g., the /b/ in buns) was detected faster when it immediately followed appropriately modified underlying coronals (e.g., ten buns pronounced /ten/), than when it immediately followed an unmodified coronal (e.g., ten buns pronounced as /ten/). Previous work using this paradigm has shown that monitoring is typically slowed when a word-initial target immediately follows a nonword (Foss & Blank, 1980). A fully labialized /n/ would produce the nonword ten. Thus, a listener might be expected to show longer monitoring latencies rather than the observed shorter ones. This suggests that in addition to anticipating the next word, participants also correctly identified the modified version of ten as ten. Furthermore, one would not be able to anticipate a labial unless one knew that the modification had been labial assimilation. This is all consistent with the view that assimilation provides information about underlying form as well as evidence of a particular type of modification.

This characterization of assimilation has important implications for the modeling of word recognition. Most template matching models of word recognition including TRACE II (McClelland & Elman, 1986), shortlist (Norris, 1994; Norris et al., 1995), and the distributed connectionist model of Gaskell and Marslen-Wilson (1997) fail to address the computational problems posed by the complex encoding of place in the speech stream. These psychologically motivated models tend to use a highly idealized input that is derived by breaking words down into abstract segments that are translated into uniform feature arrays. This imposes a one-to-one mapping between features and segments that may underestimate the mapping problem. Modeling implicitly requires idealization and simplification, and this representation of the speech stream may be necessary to make modeling practical at this time. However, the assimilation problem suggests that as future simulation models adopt more complete and naturalistic input representations, we may discover that the computational problems associated with spoken word recognition, and thus the kinds of processing mechanisms that address those problems, may change.

Feature Parsing

Feature parsing appears to be a fundamental part of word recognition. The featural distinctions that mark the difference between any two segments are dispersed in time across the speech
stream. For listeners to use this information, they ultimately have to determine which feature cues correspond to which segments.

There are two types of feature parsing problems. The first type involves the integration of multiple cues that encode a single feature of a single segment. For example, the voicing contrast between [g] and [k] is encoded in voice onset time and the value of F1 at the onset of voicing. Summerfield and Haggard (1977) demonstrated that listeners rely on both cues to determine whether a segment is voiced. Moreover, these cues show a trading relation, such that the interpretation of the value constituting one cue depends on the value of the other cue. For listeners to show a trading relationship like this, they must first determine that both cues relate to the same segment.

The second type of feature parsing problem involves pulling apart the interleaved feature cues associated with adjacent segments. Hockett (1955) captured the problem when he likened the phonemes in the speech stream to a sequence of Easter eggs on a conveyor belt, passing through wringers that “quite effectively smash them and rub them more or less into each other” (p. 210). He imagined that the listener’s job was to sort through the resultant mass and determine the sequence and identity of the eggs in the original sequence. Consider the first formant of a vowel followed by a nasal. F1 encodes information about vowel height. The value of F1 in the same vocalic interval may also encode the nasality of a subsequent segment. For the English listener, nasality plays no role in distinguishing between vowels. However, this nasality plays an important role in identifying a contrastive quality of the subsequent segment. Just as listeners must pull apart features of neighboring segments, they must also correctly integrate multiple acoustic cues that signal the value of a specific feature of a single phoneme. Given the temporal overlap of featural information for neighboring segments and the multiple loci of feature cues, it is clear that it is not a trivial problem to align feature cues with segments or timing slots. The problem becomes even more important in the face of phenomena such as assimilation that further complicate the mapping.

English place assimilation presents a clear feature parsing problem. I have argued that assimilated segments encode the underlying form of the assimilated segment and surface form of the subsequent segment. Listeners appear to make sense of such segments by associating coronality with one segment and noncoronality with the next. The results of Experiments 1 and 2 support the first half of this claim. Listeners associated coronality with the underlying form of assimilated segments. The second half of the claim, that noncoronality is associated with the next segment, is supported by other research showing that listeners use assimilation to anticipate context. Lahiri and Marslen-Wilson (1991) used a gating task to demonstrate that English speakers use vowel nasalization to anticipate postvocalic nasals. They suggested that listeners detect nasality during vowels, but are unable to associate it directly with a featural representation of the vowel because nasality is noncontrastive and thus unspecified for English vowels. Unable to associate nasality with the vowel, listeners associate it with the next segmental position. This gives them access to at least one feature of that segment before the segment is produced. Gow’s (2001) work on the use of assimilation to anticipate context can also be interpreted in this light. In the stimuli used in those experiments, English coronal place assimilation created a non-word. For example, when green is followed by a labial, it is pronounced as the nonword [gɹlm]. He suggested that listeners access green because it provides the closest lexical match with [gɹlm]. However, the labial place of [m] does not map onto the representation of green, and therefore it is associated with the segment that immediately follows green.

This analysis suggests that there is a rich, nonlinear mapping between recovered features and segmental positions. Although this view is relatively novel within the word recognition literature, it is well established in autosegmental phonology (Goldsmith, 1976). Within the linguistic literature, nonlinear, multiple, or indirect mappings between features and segments have been invoked to characterize a wide variety of phonological phenomena including place assimilation, tone spreading, and vowel harmony (Kens-towitz, 1994).

That feature parsing is a general component of word recognition seems clear. The deeper question is how feature parsing is achieved. How do listeners hear assimilated speech know which features to associate with which segments? One obvious solution would be to appeal to phonological or articulatory inference. If listeners know that labiality and coronality can coexist only within English phonology when a coronal segment is followed by an assimilating labial, they should easily infer the correct feature alignment between features and segments. However, the results of Experiment 4 suggest that listeners do not take this approach. Listeners need to consider postassimilation context to make such a mapping.

Feature alignment may instead rely on basic auditory grouping mechanisms. The Gestalt psychologist Wertheimer (1923/1938) identified a simple set of principles for grouping and segmenting perceptual elements. Subsequent researchers including Julesz and Hirsh (1972) and Bregman (1990) have argued that these principles play a role in the organization of auditory events. Listeners could group on the Gestalt principle of similarity. Labial place cues associated with a labialized coronal might group naturally with labial place cues associated with a subsequent labial if grouping took place at the level of feature cues. However, Remez, Rubin, Berns, Pardo, and Lang (1994) argued that the classic Gestalt principles cannot play a significant role in speech perception, because they would induce perceptual streaming that would prevent phonemic perception. Because listeners can group sounds into words or follow the conversation of a single speaker in a noisy environment, it appears that humans have effective auditory grouping mechanisms. It is simply unclear how to best describe these mechanisms at this point.

If a principle bearing a resemblance to grouping by similarity were to account for feature parsing, it would have to act at a more abstract level than the one addressed by Gestalt rules. For example, vowel offsets, consonant releases, and subsequent vowel onsets, though all encoding the same feature value, have different acoustic manifestations. These acoustic characteristics are similar only at the abstract level of the feature value. Moreover, this type of grouping appears to defy obvious schema-based grouping principles, because consonantal offsets from one word would not be expected to play a role in the schema of consonantal onsets for the subsequent word. Although feature parsing offers an attractive account of how listeners process speech containing instances of assimilation, more work is clearly needed to understand the mechanisms that drive this process.


### Appendix A

#### Experimental Sentences Used in Experiment 1

Below are the stimulus sentences as seen and spoken by the reader, except that prime items are shown in italics and the phonologically related coronal and noncoronal probe items are shown in parentheses.

1. He drew the *line* perfectly. (LINE–LIME)
2. He picked up the *cone* between his fingers. (CONE–COMB)
3. She didn’t know how to fix the *hen* properly. (HEN–HEM)
4. He wanted to ask what section of the museum the *loon* belonged in. (LOON–LOOM)
5. He wasn’t sure if he could ever do the *scene* properly. (SCENE–SEAM)
6. The *teen* patiently awaited the arrival of the star. (TEEN–TEAM)
7. She left the *phone* beside her tools on the workbench. (PHONE–FOAM)
8. The man watched as the *Dane* proceeded down the street. (DANE–DAME)
9. The *sun* proceeded to rise at a steady pace. (SUN–SUM)
10. He wasn’t sure who the *mat* belonged to. (MAT–MAP)
11. The neighbor knew who the *cat* belonged to. (CAT–CAP)
12. She was careful not to let her *cat* bang into the table. (CUT–CUP)
13. This time she tried to get the *right* berries for her pie. (RIGHT–RIPE)
14. The *heat* blew in the kitchen when they opened the door. (HEAT–HEAP)
15. She didn’t like the *beat* behind the lyrics of the song. (BEAT–BEEP)
16. She needs to find a way to *coat* using a different method. (COAT–COPE)
17. She stood next to the *cot* beside the window. (COT–COP)
18. They would *seat* between the rows. (SEAT–SEEP)
19. His *hit* became a big topic of conversation. (HIT–HIP)
20. His *rat* became well-known. (RAT–RAP)
21. They hadn’t had any *sleet* before tonight. (SLEET–SLEEP)
22. They were stunned by the *ban* greeting them in the next town. (BAN–BANG)
23. The *fan* glimmered in the moonlight. (FAN–FANG)
24. It often *ran* great guns for a few minutes before breaking down. (RAN–RANG)
25. The announcements *stun* guys who didn’t see it coming. (STUN–STUNG)
26. It looked like there was a *ton* growing in the back. (TON–TONGUE)
27. There’s a short *run* going in there when we finish. (RUN–RUNG)
28. He stuck the last *prawn* gamely in the pot. (PRAWN–PRONG)
29. She continued to *clean* gallantly until other people arrived. (CLEAN–CLING)
30. She refuses to *bait* gross things like that. (BAIT–BAKE)

(Appendix continues)
31. His bat ground into the dirt. (BAT–BACK)
32. Unfortunately he broke his net going for the ball. (NET–NECK)
33. He had a nightmare that the debt grew larger by the minute. (DEBT–DECK)
34. They had the lot guarded by a high tech security system. (LOT–LOCK)
35. It wasn’t necessary to blot groups out like that. (BLOT–BLOCK)
36. The knot grew tedious. (KNOT–KNOCK)
37. His height gave him hope. (HEIGHT–HIKE)
38. The bite gashed her leg. (BITE–BIKE)
39. As a rule the wait goes on for hours. (WAIT–WAKE)
40. The state gets pretty hot. (STATE–STEAK)
41. She doesn’t light gas stoves. (LIGHT–LIKE)
42. She was sure she had seen the kit go in. (KIT–KICK)
43. He almost let the spite kill her. (SPITE–SPIKE)
44. The clot grew harder to see. (CLOT–CLOCK)
45. They asked him to seat grandfather outside. (SEAT–SEEK)
46. She should have a pat go on her back. (PAT–PACK)
47. The manager plans to rid gaming operations from the clubhouse. (RID–RIG)
48. He was the bad guy on that job. (BAD–BAG)
49. There was a small lad going unnoticed. (LAD–LAG)
50. The people bade great people to join them. (BADE–BEG)
51. They often played groups around here. (PLAYED–PLAGUE)
52. The huge thud got everyone pretty worked up. (THUD–THUG)

Appendix B

Experimental Sentences Used in Experiments 2–4

Below are the stimulus sentences as seen and spoken by the reader, except that prime items are shown in italics, double slashes are present to indicate the position of the gate used in Experiment 4, and the phonologically related coronal and noncoronal probe items are shown in parentheses. The first prime item is the coronal prime that was used in Experiments 2 and 4 and the phonologically related coronal and noncoronal probe items are shown in parentheses. The first prime item is the coronal prime that was used in Experiments 2 and 4 and the second prime item is the noncoronal item that was used in Experiment 3.

1. He picked up the cone–comb // between his fingers. (CONE–COMB)
2. The students studied the clan–clam // before class. (CLAN–CLAM)
3. She didn’t know how to fix the hen–hem // properly. (HEN–HEM)
4. He wanted to ask what section of the museum the loon–loom // belonged in. (LOON–LOOM)
5. The scan–scam // proceeded for several days. (SCAN–SCAM)
6. He wasn’t sure if he could ever do the scene–seam // properly. (SCENE–SEAM)
7. The teen–team // patiently awaited the arrival of the star. (TEEN–TEAM)
8. She left the phone–foam // beside her tools on the workbench. (PHONE–FOAM)
9. She thought he was the same–same // person in that group. (SAME–SAME)
10. The owner of the fern–firm // placed first in the competition. (FERN–FIRM)
11. He wasn’t sure who the mat–map // belonged to. (MAT–MAP)
12. The neighbor knew who the cat–cap // belonged to. (CAT–CAP)
13. She was careful not to let her cut–cup // bang into the table. (CUT–CUP)
14. This time she tried to get the right–ripe // berries for her pie. (RIGHT–RIPE)
15. The heat–heap // blew in the kitchen when they opened the door. (HEAT–HEAP)
16. She didn’t like the beat–beep // behind the lyrics of the song. (BEAT–BEEP)
17. He couldn’t even sit–sip // before they started asking him questions. (SIT–SIP)
18. She needs to find a way to coat–cope // by using a different method. (COAT–COPE)
19. She stood next to the cot–cop // beside the window. (COT–COP)
20. She wondered if he had been that tight–type // before she met him. (TIGHT–TYPE)
21. They would seat–seep // between the rows. (SEAT–SEEP)
22. They hadn’t had any sleet–sleep // before tonight. (SLEET–SLEEP)
23. They had the lad–lab // mail an apology. (LAD–LAB)
24. They were stunned by the ban–bang // greeting them in the next town. (BAN–BANG)
25. It often ran–rang // great guns for a few minutes before breaking down. (RAN–RANG)
26. The announcements stun–stung // guys who didn’t see it coming. (STUN–STUNG)
27. It looked like there was a ton–tongue // growing in the back. (TON–TONGUE)
28. There’s a short run–rum // going in there when we finish. (RUN–RUM)
29. She continued to clean–cling // gallantly until other people arrived. (CLEAN–CLING)
30. She refuses to bait–bake // gross things like that. (BAIT–BAKE)
31. His bat–back // ground into the dirt. (BAT–BACK)
32. Unfortunately he broke his net–neck // going for the ball. (NET–NECK)
33. He had a nightmare that the debt–deck grew larger by the minute. (DEBT–DECK)
34. They had the lot–lock guarded by a high tech security system. (LOT–LOCK)
35. The rat–rack got caught in the doorway. (RAT–RACK)
36. It wasn’t necessary to blot–block groups out like that. (BLOT–BLOCK)
37. His height–hike gave him hope. (HEIGHT–HIKE)
38. The bite–bike gashed her leg. (BITE–BIKE)
39. She hates to rate–rake gardens. (RATE–RAKE)
40. The state–steak gets pretty hot. (STATE–STEAK)
41. She doesn’t light–like gas stoves. (LIGHT–LIKE)
42. She was sure she had seen the kit–kick go in. (KIT–KICK)
43. He almost let the spite–spike kill her. (SPITE–SPIKE)
44. Eventually his fate–fake came to light. (FATE–FAKE)
45. They asked him to seat–seek grandfather outside. (SEAT–SEEK)
46. She should have a pat–pack go on her back. (PAT–PACK)
47. The manager plans to rid–rig gaming operations from the clubhouse. (RID–RIG)
48. There was a small lad–lag growing there. (LAD–LAG)
49. With all that heat and humidity the mud–mug grew smellier every day. (MUD–MUG)
50. The people bade–beg great leaders to join the cause. (BADE–BEG)
51. I saw the guy did–dig garage foundations for a few people in the neighborhood. (DID–DIG)
52. The huge thud–thug got everyone pretty worked up. (THUD–THUG)