Frequency and Category Factors in the Reduction and Assimilation of Function Words: EPG and Acoustic Measures

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Many studies have observed phonetic and phonological differences between function words and content words. However, as many of the most commonly cited function words are also very high in frequency, it is unclear whether these differences are the result of syntactic category or word frequency. This study attempts to determine whether syntactically defined function words are indeed phonologically and phonetically reduced or assimilated when word frequency is balanced. Three experiments were designed to distinguish the relative contributions of the factors of category and frequency on phonetic and phonological processes. Overall results suggest that syntactic category and word frequency interact with phonetic and phonological processes in a more complex way than previously believed. Experiment 1 measured final t/d dropping, a reduction process, using electropalatography (EPG). Experiment 2 examined vowel reduction using acoustic measures. In Experiment 3, palatalization, an assimilation process, was examined using EPG. Results showed that t/d dropping responds to the factor of syntactic category, whereas palatalization is affected by word frequency; vowel reduction responded to both factors, with a dominant syntactic category effect and a secondary within-category frequency effect. The implications of these findings for models of lexical representation and theories of language acquisition are discussed.

KEY WORDS: function words; electropalatography (EPG); vowel reduction; palatalization; usage-based models.

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INTRODUCTION AND BACKGROUND

In most languages there is a fundamental distinction between content and function words. Content words, including nouns, verbs, adjectives, and adverbs, are regarded as carrying the dominant semantic weight of utterances whereas function words such as auxiliaries, prepositions, conjunctions, and complementizers signal relationships among different content words (e.g., Bolinger, 1975). The tendency for function words to be reduced and/or assimilated to surrounding words has been noted in both linguistic descriptions and experimental studies of production (e.g., Bell et al., 2001; Gick, 2002; Jurafsky et al., 2001; Kaisse, 1985; Kohler, 2000; Lavoie, 2000; McCarthy, 1993; Selkirk, 1972; Shi, 1995/96; Shi et al., 1998; van Bergen, 1993; Zwicky, 1970). However, in linguistic analyses, function words are generally considered as belonging to a distinct category from content words. Despite this categorization, it is unclear whether the reduction and assimilation observed for these words are due to the fact that they are function words or to the fact that they are highly frequent words. There are several words at the edge between function words and content words that are not so plainly definable, such as "underneath," "however," "nevertheless," and "just." Some are clearly definable as function words based on their syntactic/semantic properties, but researchers are often reluctant to include them as function words. This is because they do not behave phonetically/phonologically like typical function words. As it is unclear how a factor such as frequency interacts with category, there exists the possibility that the function word behaviors can be attributed to frequency differences rather than category differences. The current study attempts to tease apart the two factors by examining the production of function words versus content words in conditions in which category and frequency are balanced.

The reduction and assimilation of function words as opposed to content words (defined as distinct syntactic categories) have been discussed by linguists in phonological descriptions of different languages (e.g., Kaisse, 1985; Kohler, 2000; McCarthy, 1993; Selkirk, 1972; Zwicky, 1970). For instance, in analyzing the intrusive /r/ in Eastern Massachusetts English (e.g., in "saw Ed") /r/ is described as being inserted due to the surface constraint prohibiting the word final short vowel to be directly followed by a word with initial vowel. McCarthy (1993) reported that the only exception to this rule is after a function word in non-phrasal final position. Thus, intrusive /r/ does not occur between words in "to Ed." In essence, by blocking the intrusive /r/, function words violate a general surface constraint but in turn avoid taking on a more complex form.

In addition to the linguistic descriptions, recent production studies have examined various types of reductions or assimilations in spontaneous
Frequency and Category Factors in the Reduction and Assimilation of Voiced Stops

In an X-ray study of American English schwa (Gick, 2002), the schwa in function words showed no pharyngeal displacement from resting position for one subject, whereas tongue root retraction was observed for the schwa of content words, suggesting that the truly “neutral”, non-specified schwa as described in English phonology is only evident for function words. Indeed, in contrast to content words, function words have been found to be reduced acoustically (e.g., vowel duration, amplitude, F1/F2 centralization) and phonologically (e.g., number of syllables per word, number of segments for syllable onset, nucleus and coda; unmarkedness in the application of phonological rules) in spontaneous speech recordings of three typologically different languages – English, Mandarin and Turkish (Shi, 1995/96; Shi et al., 1998). In another study with controlled stress contexts, the reduction of function words was observed to occur not only when preceded by a stressed syllable, but also when preceded by an unstressed syllable (Lavoie, 2000). In Lavoie (2000) all of the five speakers produced the weak form of “for”, with the final /r/ dropped when the word was preceded by a stressed syllable such as in “bouTIQUE for”. The /r/ dropping, as in the case of intrusive /r/ blocking described in McCarthy (1993), produces a more reduced form of the function word. Lavoie (2000) reported that even when preceded by an unstressed syllable such as in “...BOOty for”, the majority of the speakers produced a weak “for” (short in duration), yielding a strong-weak-weak pattern at the sentential level rather than an alternating strong-weak-strong pattern. The reduction of function words is also robust in utterances where the vowels of function words per se are each well matched with those of content words (van Bergen, 1993). In Dutch, which has a stress system comparable to that of English, mono-syllabic function words with underlyingly specified primary stress were produced with vowel quality (measure: F1/F2) as reduced as the unstressed syllable (matched in vowel type with function words) of bi-syllabic content words, and a stress effect was only found within the category of content words (van Bergen, 1993). Using comparable examples in English to illustrate, van Bergen explained that the vowel quality of the function word “can” would be as reduced as that of the first syllable in “canTEEN”, and more reduced than the first vowel in “CANdy” even though he considered the vowel of the function word and that of the content word “CANdy” are both specified underlyingly with the same primary stress (in contrast with the first vowel in “canTEEN”). (In this English illustration, van Bergen may not have considered dialectal variants of the vowels in “can” and “canTEEN”, which might be quite different in some speakers). In addition to vowel quality, van Bergen found that the...
vowel duration of function words is shorter than that of all content words regardless of the stress specifications of the first syllable, i.e., "can" would be shorter than both "can'TEEEn" and "CANDy". Hence, van Bergen concluded that the effect of word category appeared to have overruled the effect of stress.

Although the authors for the production studies discussed above considered the reduction as primarily the effect of category, none of these studies controlled for word frequency. Therefore it remains unclear whether the reduction was the result of frequency or category factors.

Frequency effect on reduction and assimilation of words in general has been well observed, although most studies have been conducted without the control for word categories. In general, high frequency words are more prone to reduction and assimilation processes. For instance, word frequency significantly affects the rate of word-final t/d deletion (Bybee, 2000; Jurafsky et al., 2001). Cooper and Paccia-Cooper (1980) also found that word frequency influences the rate of palatalization. Palatalization could occur when an alveolar stop, /t/ or /d/, is followed by a palatal, i.e., the glide /j/. The alveolar stop becomes an affricate. For example, in the phrase "but you," "but" is the coronal-final word, "you" is the /j/-initial word, and the result is that /t/ becomes an affricate. Cooper and Paccia-Cooper found that the rate of the palatalization rule application in English was related to the frequency of the /j/-initial word. In a study that did control for syntactic category, Gregory et al. (2001) found that high frequency content words were shorter in duration than low frequency content words, although they did not examine function words.

Factors other than frequency which affect reduction have also been reported. Speech rate, and probabilistic/semantic relations with neighboring words are positively related to the degree of reduction such as vowel neutralization and vowel shortening; phonetic environment and gender also affect reduction (Bell et al., 2001, Gregory et al., 2001, Jurafsky et al., 2001). In addition to findings from acoustic measures and perceptual coding, electropalatographic (EPG) studies on consonant sequences revealed that stops in coda position are more likely to be reduced than in onset position, and that stops are more overlapped by a following consonant than fricatives. EPG studies also showed that the palatalization rule is sensitive to various factors besides frequency. Speakers produce less palatalization when there is a verb gap between the coronal-final and /j/-initial words (Cooper & Paccia-Cooper, 1980). For instance, palatalization was unlikely between "guide".
The bus driver will take your brother and guide your sister because there is a verb gap between the two words. In contrast, /d/ in “guide” was frequently palatalised in “The bus driver will take your brother and then guide your sister” as no verb gap occurs between “guide” and “your”. Speakers also produce more palatalization when stress is on coronal-final than /j/-initial word (Cooper & Paccia-Cooper, 1980). In recent years the effect of frequency on reduction and assimilation processes has received much attention, in particular with respect to its theoretical consequences/importance on the grammar. It has been well documented cross-linguistically that historical sound changes often affect high frequency words first and spread gradually to lower frequency words (e.g., Fidelhotz, 1975; Hooper, 1976; Leslau, 1969; Phillips, 1980). These changes typically involve reduction, deletion and assimilation, which are considered as physiologically/motivated (Phillips, 1984), that is, related to production. The continuous changes from old to new forms affect the lexicon item by item with high frequency words changed first, producing small gradual phonetic changes in the lexical representation of the affected items (Bybee, 2000). Bybee illustrated such gradual changes with examples such as “every”, “memory” and “mammary”. The sound change of vowel deletion is complete for the high frequency word “every”, is intermediate for the mid frequency word “memory” (realized as a syllabic /r/), but has not affected the low frequency word “mammary”. There are also between- and within-speaker variable forms for certain items, exhibiting different degrees of changes. Bybee (2000) treated the frequency effect on the rate of word-final t/d dropping in the same fashion as the frequency-related lexical diffusion in historical sound change. Following the original theoretical framework of Langacker (1987), Bybee indicated that phonetic details for varying forms of a word must exist in the representation. The on-going experience of producing and perceiving (including self-monitoring) a word is directly tied to the dynamic forms of its lexical representation. Phonemes, which are abstracted from specific instances in the lexical representation (with their phonetic details), only exist at a higher level to capture/represent the general properties of the lexicon. Within this framework Bybee (2000) suggested that word frequency, which is very important in production and perception, is an integral part of the grammar. Similarly, in Pierrehumbert’s (2001) formal model based on the Exemplar Theory, she considers word frequency information as intrinsic to the mechanism and implicitly encoded in the model. In essence, these researchers present a usage-based view, which departs considerably from standard generative models in terms of lexical representation and its relation to production and perception, as well as the very notion of competence and performance.
Word frequency, which is regarded by generativists as a peripheral factor, plays a central role in the structure of the lexical representation within the usage-based models. On the other hand, factors other than frequency such as category, stress and speech rate are not specially built into these models (e.g., Pierrehumbert, 2001).

As discussed above, function words as a distinct syntactic category differ phonetically and phonologically from content words, with function words more likely reduced and assimilated. However, most function words and content words differ along a number of axes, including syntactic category, frequency, etc., making it unclear which factors are responsible for these observed differences. The purpose of the present study is to isolate the factors of frequency and category, while controlling for rate and stress, and in doing so to determine whether the phonetic and phonological processes of reduction and assimilation are dependent on word frequency or grammatical category.

Using electropalatography (EPG) and acoustic measures, we examined three phonological/phonetic processes: (1) final -t/d dropping, a common reduction process whereby the closure gesture associated with a final coronal stop is reduced in magnitude and/or duration (as in the often reduced final coronal in, e.g., could), (2) vowel reduction (vowel duration and intensity), and (3) palatalization, a process of assimilation, whereby the constriction location of a final coronal stop is affected by the presence of a following palatal glide (e.g., palatalization of final /t/ in casual productions of against you). This process has been studied in some detail by Zsiga (1993/1994, 1994, 2000). The results of these analyses would have implications for questions relating to the role of frequency in the grammar, the nature of lexical representation, and the interaction of representation, production and perception.

**EXPERIMENT 1: FINAL-T/D DROPPING**

**Methods**

An electropalatography (EPG) study was conducted to examine the contributions of word frequency and category to final -t/d dropping, a reduction process. EPG was chosen for this study because the output can be used to distinguish fine differences in closure presence, duration, degree, and location. The use of these measures will be discussed below.

**Subjects**

Five adult native speakers of North American English participated in the EPG study, one male and four female. The native dialect regions...
Frequency and Category Factors in the Reduction and Assimilation of each subject were as follows: subject BB (female), British Columbia; subject IW (male), Ontario; subject KD (female), Ontario; subject KK (female), Philadelphia; and subject PB (female), various Canada and Ohio. The subjects were not informed about the purpose of the study until the data collection was complete. All five subjects were phonetically trained.

Apparatus

EPG data was collected using a Queen Margaret College EPG3 hardware/software system running on a Pentium PC. The system has a collection rate of 100 frames per second. Each subject had an electropalate specially crafted to fit a dental mold. The palates have 62 electrodes arranged in seven rows of eight and one of six (the most anterior row; see Fig. 1).

The EPG3 system includes simultaneous collection of acoustic data, which allowed events of interest to be easily located in the EPG data. The output of the EPG3 system is a stream of frames similar to those in Figure 1, with each successive frame showing the contact pattern of the tongue with the electropalate at successive instants in time.

Stimuli

Sets of phonetically minimally different words were selected to ensure comparable environments of coarticulation and to allow for comparison of (1) high and low frequency words within category, and (2) function and content words at a high or low frequency. Word frequencies were taken from the COBUILD corpus (University of Birmingham) of spoken UK English <http://titania.cobuild.collins.co.uk/wbanks.html> accessed in August 2002.

Fig. 1. An EPG frame depicting a /t/-closure. The white cells indicate tongue contact, the shaded cells indicate no contact.
A set of three words positioned hand over hand and the single complete sentence could be divided by English, to reduce to 10 complete.

To control for rate, the sentences were made up of sequences of iambic (weak-strong) feet, with the target word in weak position. This created a uniformly low stress condition for both the content and function words (the latter of which normally appear relatively unstressed). Rate was also controlled by using a flashing LED metronome, which provided one beat per two iambic feet, at rates of 50 (slower than normal speaking rate) and 76 (approximately normal speaking rate) beats per minute (bpm). The rate of one beat per two feet was used to avoid the "sing-song" quality of speech that was found to accompany a one-beat per foot approach in our pilot trials (accent marks are placed on words in (1) below to indicate words where the metronome beat landed). As discussed above, it was important to control for rate and stress, as these factors influence reduction processes. Syntactic structure was also controlled for by having the target and following word within the same phrase, VP or NP. Therefore, the two words were syntactically as similar as their different semantic functions allowed, and were not separated across a strong syntactic domain.
The following are some example sentences for each condition:

<table>
<thead>
<tr>
<th>Subject</th>
<th>Normal Speaking Rate (76 bpm)</th>
<th>Slow Speaking Rate (50 bpm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td><em>Thāt's a thing good boys'll do.</em></td>
<td><em>It hinh that Bev could pack the trunk.</em></td>
</tr>
<tr>
<td>B</td>
<td><em>It hinh that Tom should brake a glass.</em></td>
<td><em>It hinh the play's best parts are gone.</em></td>
</tr>
<tr>
<td>C</td>
<td><em>It hinh that Faye must pick a house.</em></td>
<td><em>The slower speed condition (50 bpm) was observed to produce a somewhat unnaturally slow speech rate.</em></td>
</tr>
</tbody>
</table>

The main effect across subjects for total contact area (i.e., the total number of contact cells within the most anterior four rows) using...
one-way analysis of variance (ANOVA) is significant for good/could/should, $F(2, 267) = 3.48; p<.05$, but not for the second set best/must. Post-hoc tests (Fisher's PLSD) show that good had significantly more closure than could ($p = .0088$), with no other significant differences between pairs within that set. Even though the difference between good and could seemed to suggest a category effect, the results that good was not different from should, and that best was not different from must, disconfirm this conclusion. Furthermore, the results showed no frequency effect as could and should were not different. Therefore, Total contact area was not a reliable measure of either the category or frequency effect.

For the analysis of closure presence, each target word production was coded in terms of whether there was a complete closure or not.

![Graph showing mean closure presence for each target word (across subjects) during final alveolar stop, 76 bpm condition.](image_url)
Chi-square tests showed that good and should, different in both category and frequency, are significantly different in closure presence ($X^2(1) = 7.701, p = .0055$). More importantly, good and could, which have similar frequencies, were also significantly different ($X^2(1) = 6.087, p = .0136$). These results indicate a category only effect. This was further confirmed by the finding that best and must, which are comparable in frequency but different in category, showed a significant difference in closure presence ($X^2(1) = 12.857, p = .0003$). The lack of frequency effect was particularly clear in the result that could and should showed no difference in closure presence ($X^2(1) = .102, p = .7497$).

Function words such as could, should and must were much more likely to have zero closure (i.e., t/d dropping) than content words such as good and best.

Bar graphs of mean percentage closure presence across subjects during alveolar stop are shown in Figure 2. Note that the overall rate of closure presence for the best/must set is lower than that of the good/should/could set. This may be due to coarticulation with the preceding fricative.

In general, based on the results of closure presence, it can be concluded that the t/d dropping process is sensitive to syntactic category. That is, the final consonant of function words such as could and should is significantly more reduced than that in content words such as good. This result was robust even when frequency was balanced.

**EXPERIMENT 2: VOWEL REDUCTION**

**Methods**

An acoustic study was conducted to examine the contributions of word frequency and category to the process of vowel reduction. Acoustic analysis is the simplest and most accurate method for analyzing vowel duration and intensity, the two measures that we used to determine the degree of vowel reduction.

**Subjects**

The subjects were the same 5 subjects as described for Experiment 1.
their mouths about four to six inches away from the microphone. This distance was not strictly controlled and may therefore be assumed to vary randomly across all tokens within any given speaker. Sound files for 4 of the subjects were transferred to a Macintosh G4 for acoustic analysis. The sound files for the fifth subject were analyzed directly on the Pentium PC.

Stimuli

The stimuli for this experiment were identical to those described above for Experiment 1.

Analysis

To be consistent with the electropalatograph study, we only analyzed the normal speaking rate (76 bpm). The acoustic analysis focused on the vowels in each of the stimuli (good, could, should, best, and must). Two acoustic measures were made: one of vowel duration and one of vowel intensity. Both of these analyses were performed using a Praat script written for this experiment. To enable this automated analysis, the start and end points of the vowels in question were labeled by hand. Using the waveform of each word, the start point of a given vowel was placed at the nearest zero-crossing to the start of the periodicity of that vowel. Similarly, the end point was placed at the nearest zero-crossing to the end of the vowel periodicity.

After all 450 vowels (90 sentences × 5 subjects) to be analyzed were labeled, the script first calculated the duration (in msec) of each vowel. Then the midpoint of each vowel was automatically extracted and the intensity (in dB) at that point was calculated using cubic interpolation. For both measures, it was possible to combine data across all 5 subjects. This enabled an averaging of 90 tokens for each of the five stimuli words. One of must had to be removed due to noise in the signal.

Results

For vowel duration, the main effect across subjects using one-way ANOVA is significant for both good/could/should, F(2, 267) = 33.926; p< .0001, and best/must, t(177) = 7.81; p< .0001. Post-hoc tests (Fisher’s PLSD) show significant differences between all pairs within each of the two stimulus sets (p< .0001 for all pairs within each set, except could, should, p = .0067). In the first set, good had the greatest mean vowel duration, and was significantly different from
Both and could, indicating a category effect, the effect was also present in the second set of stimuli, as shown in the significant difference between best and must in the second set of stimuli. Within function words in the first set, could and should were significantly different. The lower frequency word should had a longer mean vowel duration than the higher frequency word could, suggesting a within-category frequency effect. Bar graphs of mean values are shown in Figure 3.

For vowel intensity, the main effect across subjects using one-way ANOVA is significant for both good/could/should, \( F(2, 267) = 36.624; p < .0001 \), and best/must, \( t(177) = 4.266; p < .0001 \). Post-hoc tests (Fisher's PLSD) again show significant differences between all pairs within each of the two stimulus sets (good versus could, ...
Mean Vowel Intensity (dB)

Fig. 4. Mean vowel intensity, 76 bpm condition, with standard errors.

$p<.0001$; good versus should, $p<.0001$; could versus should, $p=.0021$; and best versus must, $p<.0001$). In the case of best/must, the results mirror those of vowel duration: the content word best had greater intensity than the function word must. Similarly, for the first set, good had the greatest vowel intensity, significantly different from both could and should, indicating a category effect. Within function words, could and should were significantly different. However, in this case the higher frequency function word could had a greater vowel intensity than the lower frequency function word should. This unexpected reversal of vowel intensity could be due to the production difference of the initial consonants of the two words. In could the initial stop involves a greater buildup of air pressure than that...
Frequency and Category Factors in the Reduction and Assimilation of the initial fricative in should. This might account for the higher vowel intensity in could versus should. Bar graphs of mean values are shown in Figure 4.

In general, the results of vowel duration and vowel intensity show a clear, dominant effect of syntactic category, and a secondary within-category frequency effect (in the vowel duration measure).

EXPERIMENT 3: PALATALIZATION

Methods

A second EPG study was conducted to examine the contributions of word frequency and syntactic category to palatalization, an assimilation process. The same subjects and apparatus were used for this experiment as for Experiment 1 above, and thus they will not be repeated here.

Stimuli

One set consisting of four /j/-words (definition discussed above) was used (see Table III; frequency is given in parentheses):

Table III. Target Words for Palatalization, with their Respective Categories and Frequencies

<table>
<thead>
<tr>
<th>Lower frequency</th>
<th>Higher frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Function</td>
<td>Non-function</td>
</tr>
<tr>
<td>Used to (3000)</td>
<td>Union (301)</td>
</tr>
</tbody>
</table>
Shi et al. noted that dropping nasals was not be controlled using the same method as for final-
t/d dropping in Experiment 1. Instead, subjects were instructed to read the sentences at
what they and the experimenter agreed as a normal speaking rate. Speaking rate was monitored
orally by the experimenter and corrected when necessary to maintain a consistent rate across
and within subjects. Post-recording duration analysis on a randomly selected sample confirmed
that the number of syllables per second was generally comparable among stimuli sentences
(mean: 5.09; SD: 0.48). As with prosodic uniformity, complete syntactic uniformity was impossible.
Sentences were constructed such that emphatic stress on the coronal-final word seemed reasonable.
Capitalized letters were used for the words receiving primary stress in the sample sentences shown in (2):

(2) But the team we're playing AGAINST used to win a lot.
This was the FIRST union, not the second.
But you should TRUST unit plans.
But I think I'm AGAINST you and your ideas.

There were three blocks comprising nine sentences each. Four of the nine sentences within each block were used for analyses. The remaining five sentences within each block were excluded for the following reasons. The first and last sentences in each block were removed to reduce list effects. There were originally sentences with “about” as the first word of the target pair. As these may be too different from the other first words, which all ended in /st/, we decided to only retain the sentences with /st/ words. Finally, one sentence per block contained “/r/” in the second word of the target pair, so this word was excluded. Thus, in each block, four sentences remained.

As shown in (2) above, each of these four sentences had a word ending in /st/ followed by a different /j/-initial word under discussion. This three-block set was then repeated five times giving a total of 60 sentences to be analyzed for each of the five speakers. Since there were 15 sentences for each of the four words (i.e., you, union, unit, used to) and since there were five speakers, the total number of sentences for analysis for each of the /j/-initial words was 75.

Analysis
As in Experiment 1, a single frame was isolated and extracted for each token by the experimenter. The final /t/ of the preceding word was the target for analysis. Where there was no closure, the frame with the maximum contact was
It was assumed that the closure location of a palatalized /t/ should be less anterior than that of an unpalatalized /t/. Thus, an unpalatalized segment was expected to have maximum contact in the first one or two rows (most anterior), while a palatalized segment would have less contact in this region. Therefore, the amount of contact in the first row or two (depending on constriction location for each subject) was used to express the amount of palatalization (measured in the total number of cells of contact). For three subjects with relatively anterior average closures, BB, IW, and KD, contact in the first row only was sufficient to measure anteriority; for the remaining two subjects, KK and BB, contact was measured in the first two rows. Due to this variability between subjects, the amount of closure was normalized to a z-score. This allowed the data to be combined across subjects.

Results

The z-scores representing the amount of palatalization of the final coronal were analyzed with respect to the following /j/-initial words of different frequencies and syntactic categories (i.e., you, used to, union, and unit). A one-way ANOVA revealed a main effect of words across subjects, $F(3, 287) = 3.323; p = 0.0202$. Bar graphs of mean values are shown in Figure 5.
Post-hoc tests (Fisher’s PLSD) show that you was significantly less anterior (more palatalized) than union ($p = .0256$), unit ($p = .0103$), and used to ($p = .0060$). There were no significant differences among union, unit and used to. Thus, the highly frequent word you was much more subject to palatalization. Palatalization appeared to be only affected by word frequency rather than category.

CONCLUSION AND DISCUSSION

The aim of this study was to examine whether the phonological processes of t/d dropping, vowel reduction, and palatalization respond to differences in word frequency or in syntactic category. That is, are reduction and assimilation likely to occur for high frequency words (as opposed to low frequency words), or for function words (as opposed to content words)? The results showed a complex picture. The EPG finding on t/d dropping revealed that this reduction process is unambiguously responsive to the factor of syntactic category. This result contrasts with Bybee (2000) where she reported a frequency effect for the variation in t/d dropping. However, as Bybee (2000) did not control for the factor of syntactic category, it was possible that at least some of the high frequency words, which were more prone to t/d dropping, were in fact function words. On the other hand, we found that the assimilatory process of palatalization is responsive to the factor of word frequency factor. In addition, acoustic measures of vowel reduction (vowel duration and intensity) yielded a clear, dominant syntactic category effect and a secondary (in the vowel duration measure) within-category frequency effect.

Given the above complex pattern of results, it is not surprising that the effects of function and frequency words have often been confounded or merged in previous literature, as discussed above. Existing linguistic descriptions as well as production studies, as discussed earlier in the article, have shown that function words as a distinct class of words are often subject to reduction and assimilatory processes. However, these are generally also the most highly frequent words. Thus, either the category difference or word frequency difference could account for the tendency for reduction and assimilation. The current study shows that both factors are present, explaining the difficulty in separating function words and high frequency words. It can no longer be assumed that reduction and assimilation processes are all and only correlated with one of these factors. Specifically, our results suggest that superficially similar processes make reference to different information at different levels. Processes such as palatalization make reference to word frequency, while a substantial
treated as outside of the grammar in standard linguistic theory. Certain other processes such as t/d dropping make reference to syntactic category, which is information central in the grammar. Speech production theories therefore must include both factors in their model description.

The present findings have direct relevance to the current models of lexical representation which consider frequency as a crucial part of the grammar (e.g., Bybee, 2000; Pierrehumbert, 2001). Departing from standard models, these current theories regard production, perception and representation of lexical items as directly linked, with all three components shaped crucially by frequency of use. In Bybee's model (Bybee, 2000), high frequency words are particularly vulnerable to variations in spoken forms (such as minimization and assimilation); these changes in forms are perceived and stored in the mental representation, which in turn affect production; the entire process could cause historical sound changes. Our results on the process of palatalization help to clarify the role of word frequency in speech production. Furthermore, we show that syntactic category must also play a role. Thus, we suggest that variable spoken forms can be a consequence of either a word being frequently used, or a word being a function word, or both.

The fact that reduction can be a result of syntactic category presents a different way of looking at variable forms of a lexical item. Reduction is intuitively assumed to be linked to highly frequent usage, as high frequency words could lower the recognition threshold thus could be produced with less care (Morton, 1969). Our results demonstrate that syntactic category information, like frequency, could also yield reduction. We believe that the tendency for function words to be reduced (as in the case of t/d dropping) can be attributed to their low semantic load and high predictability, which could be another way of lowering the recognition threshold. Jurafsky et al. (2001) showed that high predictability of words relative to their neighboring words is related to vowel reduction. Thus, if lexical representation is assumed to be potentially altered by frequency of usage, then syntactic category information should also be able to affect the structure of the lexical representation. Hence, usage-based models need to take into consideration the category information and its contribution to the structure of lexical representations.

The results of our study have additional implications for children's acquisition of syntactic categories. One of the difficult tasks facing children early in language development is the formation of basic syntactic classes such as nouns, verbs, auxiliaries, etc. Phonological and phonetic differences between content and function words have been proposed to help infants bootstrap into the system of syntactic categories (Shi, 1995/96; Karimi & de Marneffe, 2003). The results of our study suggest that the category information, like frequency, could also play a role in the acquisition of syntactic categories.
Indeed, infants at birth demonstrate the ability to categorically discriminate content from function words when these two classes of words were presented to them in a High-Amplitude Sucking paradigm (Shi, Werker & Morgan, 1999). At 6 months of age infants begin to attend more to content words over function words (Shi & Werker, 2001) based on acoustic and phonological properties (Shi & Werker, 2003). These studies argue for the view that the production differences of content and function words in adult speech input could help infants make this initial binary distinction and form their listening bias for content words. These abilities prepare infants in other important language learning tasks such as the formation of other refined syntactic classes, initial word segmentation and learning of earliest word meanings.

One major criticism of the above view of bootstrapping has been that the phonological and acoustic differences may not in fact be due to the distinction between content and function words, but rather may be determined by word frequency. This criticism is worth considering given that the phonological and acoustic differences may not be solely determined by word frequency in other studies. For instance, in some cases, word frequency may influence phonological processes such as t/d dropping, palatalization, and vowel reduction (vowel duration and intensity). Our present study shows that when category and word frequency are well balanced, a clear category distinction is present for certain phonological processes such as t/d dropping. Unambiguous information about the categories of content and function words is thus available in adult speech, and we propose that this type of information provides infants with a means of breaking into early syntax.

Our study also controlled for factors such as speech rate, stress, phonetic context, and where possible, syntactic environment. Nevertheless, there could be other factors that affect the reduction and assimilation processes. For example, social acceptability, pragmatic factors, and the degree of certainty about the speech input may also influence these processes.

In sum, the current study shows that different processes of reduction or assimilation in adult speech are sensitive to syntactic category or word frequency. Specifically:

1. t/d dropping, a reduction process, is sensitive to the factor of syntactic category (word-final coronals in function words are more likely to be deleted than in content words of a comparable frequency).
2. Palatalization, an assimilation process, is sensitive to word frequency (high-frequency /j/-initial words, regardless of word category, are more likely to induce palatalization in preceding coronal-final words).
3. Vowel reduction (vowel duration and intensity) is sensitive to a dominant syntactic category effect and a secondary frequency effect (shown clearly in the reduction of vowel duration) for words within the function-word category.

These results suggest that factors arguably in distinct realms of grammar influence speech production in different ways.
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APPENDIX A. STIMULI SET FOR EXPERIMENT 1 (t/d - DROPPING) AND EXPERIMENT 2 (VOWEL REDUCTION)

That’s a thing good I think that John could
boys’ll do. buy my car.
That’s a pad good I think that Bev could
paws’ll have. pack the trunk.
That’s a ship good I think that Tom could
bays’ll have. break a glass.
That’s a hive good I think that Mike could
bees’ll have. peel his lime.
That’s a pod good I think that Scott could
peas’ll have. beat the champ.
That’s a price good I think that Faye
buys’ll have. could pick a house.
That’s a fruit good I think that Pam could
pies’ll have. bike to school.
That’s a shine good I think that Nell
parts’ll have. could pop your bubble.

I think that John should I think the school’s best
buy my car. boys are smart.
I think that Bev should I think the dog’s best
pack the trunk. paws are soft.
I think that Tom should I think the state’s best
break a glass. bays are blue.
I think that Mike should I think the hive’s best
peel his lime. bees are fat.
I think that Scott should I think the vine’s best
beat the champ. peas are green.
I think that Faye should I think the shop’s best
pick a house. buys are sold.
I think that Pam should bike to school. I think that the cook's best pies are sweet. I think that Nell should pop your bubble. I think that the play's best parts are gone. I think that John must buy my car. I think that Bev must pack the trunk. I think that Tom must break a glass. I think that Mike must peel his lime. I think that Scott must beat the champ. I think that Faye must pick a house. I think that Pam must bike to school. I think that Nell must pop your bubble.

APPENDIX B. STIMULI SET FOR EXPERIMENT 3 (PALATALIZATION)
But this was the FIRST unit produced here. I think I trust you now that I know you. But I think that's against union policies. But the team we're playing against used to win a lot. This was the first union, not the second. But I think I'm against you and your ideas. But you should trust unit plans. But I thought we were against unit pricing. I think that first you can look, then decide. Only those with trust used to cross the bridge.
Frequency and Category Factors in the Reduction and Assimilation


