

KNOWLEDGE OF GRAMMAR, KNOWLEDGE OF USAGE:
SYNTACTIC PROBABILITIES AFFECT PRONUNCIATION VARIATION

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Frequent words tend to shorten (see e.g. Schuchardt 1885, Hooper 1976), as do words that have a high probability of occurrence given a neighboring word (Jurafsky et al. 2001). This tendency has been cited in support of the claim that probabilities are an inherent part of grammar, and of syntax in particular. There is widespread consensus, however, that the syntax of natural languages cannot be captured in terms of item-to-item transitions (Chomsky 1957). Therefore, unless one considers probabilities of syntactic structures, rather than particular combinations of neighboring words, pronunciation variation cannot be said to reflect probabilistic effects in syntax. In this article, we report a case of pronunciation variation that reflects contextual probabilities of syntactic structures. The relevant probabilities are based on the probability of a given syntactic structure, given a particular verb. We show that these probabilities affect American English /t,d/-deletion, as well as the durations of words and phrases. Our results are consistent with the notion that knowledge of grammar includes knowledge of probabilities of syntactic structures, and that this knowledge affects language production.*

1. INTRODUCTION. Frequent words tend to shorten (see e.g. Schuchardt 1885, Hooper 1976), as do words that have a high probability of occurrence given a neighboring word (Jurafsky et al. 2001). This tendency has been cited as evidence for usage-based approaches to language variation and change, and more generally for the claim that probabilities are an inherent part of grammar, and of syntax in particular (Bybee 2001, Jurafsky 2003a). The available evidence, however, fails to establish a role of probabilities in syntax for two reasons. First, '[t]he probabilities may be more a function of the meaning that one wants to convey than of some inherent property of the structure itself' (Newmeyer 2003:697). Consequently, observed probabilistic effects may be due to factors that lie outside of the realm of grammar, unless meaning is controlled for. Work in the variationist tradition has long argued that variation is part of the mental grammar (see e.g. Henry 2002); psycholinguistic work has shown that language processing appears to be sensitive to syntactic probabilities. Yet both of these strands of research are in principle vulnerable to the objection raised by Newmeyer; High-probability phrases or sentences might describe scenarios that are frequently the case; therefore, if the behavior of high-probability forms differs from that of low-probability ones, this difference may be due to the difference in meaning, rather than any property recorded in the grammar. The second reason is that existing evidence of probabilistic pronunciation variation is based on probabilistic relations between particular words or segments. Are these word-to-word or sound-to-sound probabilities the only probabilities that speakers know? If it is indeed the case that '[p]robability may play a role in accessing *structures*

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from the mental lexicon OR GRAMMAR' (Jurafsky 2003b:40, emphasis added), then we should expect probabilistic effects based on the likelihood of grammatical structures. However, there is widespread consensus among linguists that, whatever syntactic model one adopts, syntactic regularities make reference to syntactic categories, such as noun phrases or verb phrases, rather than to sequences of particular words. Moreover, the syntax of natural languages cannot be adequately described in terms of transitional probabilities among syntactic phrases but must make reference to hierarchical structure and syntactic relationships (Chomsky 1957, Miller & Chomsky 1963). Therefore, unless it can be shown that pronunciation variation reflects probabilities of syntactic structures and relations, such variation cannot be said to reflect probabilities based on syntax. While knowledge of syntax is only one aspect of knowledge of grammar, it is widely held to be a very important part of linguistic competence; therefore, if no effects of syntactic probabilities existed, this would cast serious doubt on the claim that knowledge of grammar includes knowledge of probabilities.

In this article, we establish effects of probabilities on pronunciation that are not attributable to meaning (e.g. to the likelihood with which a sentence is true) and that are based on syntactic relationships. In particular, we show that the conditional probability of syntactic structures affects the pronunciation of words in those structures. Our results are consistent with the view that speakers' knowledge of such probabilities forms an inherent part of their knowledge of grammar.

2. PROBABILITY AND PRONUNCIATION VARIATION. We begin by reviewing the evidence for the role of probabilities in pronunciation variation. A generalization that has emerged from this evidence is that high-frequency and high-probability forms tend to be phonetically reduced (Jurafsky et al. 2001). Given this evidence, we argue that pronunciation variation clearly reflects probabilities and therefore provides a promising means of investigating probabilistic effects at abstract grammatical levels.

It has long been noted, both in studies of diachronic language change and in studies focusing on synchronic variation, that frequent words tend to be shorter than infrequent ones in the lexicon, and that frequent words are subject to phonetic reduction and shortening (Schuchardt 1885, Fidelholz 1975, Hooper 1976, Wright 1979, Balota & Chumbley 1985, Whalen 1991, Gregory et al. 1999, Jurafsky et al. 2002, Bell et al. 2003).¹

High-frequency multi-word expressions also tend to shorten. For example, Bybee (2000) attributes contractions such as *I'm*, *you're*, or *don't* to the high frequency of the corresponding nonreduced expressions. Examples of this sort are common (see Krug 1998, Bybee 2000, 2001, Ellis 2002) and provide motivation for believing that frequency effects exist at the level of multi-word expressions.

Regardless of frequency, words also tend to shorten if they are said more than once in a given discourse (Fowler & Housum 1987, Fowler 1988, Shields & Balota 1991, Fowler et al. 1997, Bard et al. 2000). Some authors attribute this tendency to articulatory practice effects, whereas others focus on the role of informational load, which is greatest for words that are being introduced into a discourse for the first time. We return to the sources of durational shortening in repeated and frequent words in the discussion of our results. In the present context, we note only that neither repetition nor predictability within a discourse makes reference to syntactic or other grammatical structure.

¹ It is not clear in all cases if 'shortening' is best thought of as the generation of a reduced form or as selection of a short form from among variant forms in the lexicon, perhaps from among a very large collection of exemplars stored in the lexicon (Pierrehumbert 2001).

In addition to overall durational shortening, phonetic reduction can take the form of segment deletion. For example, unstressed schwa followed by a resonant tends to be reduced in American English, and is frequently deleted completely. Hooper (1976) suggests that this reduction is especially likely in frequent words, such as *memory* and *family*, and unlikely in low-frequency words of similar form, such as *mammary* and *homily*. A recent corpus study (Patterson et al. 2003) confirms that frequency is a significant, though weak, predictor of schwa deletion. Another example of segmental deletion affected by frequency is final /t,d/-deletion in American English, which is particularly common in high-frequency words such as *just*, *and*, and *went* (Labov 1972, Neu 1980). Several recent studies (Gregory et al. 1999, Bybee 2000, Jurafsky et al. 2001) have shown that lexical frequency is a significant predictor of /t,d/-deletion, consistent with the generalization that high frequency promotes shortening or the selection of shortened variants from the lexicon.

Neighboring word-to-word transitional probabilities, such as the probability of a word given the previous word, also promote durational shortening and segment deletion, including /t,d/-deletion. For example, the word *court* tends to be phonetically reduced in the expression *Supreme Court*, as a function of the high conditional probability of *court*, given *supreme*, according to Gregory et al. 1999 and Jurafsky et al. 2001. These recent observations, based on the Switchboard corpus of telephone conversations (Godfrey et al. 1992, Greenberg et al. 1996), confirm and extend observations on shortening and reduced intelligibility of words whose identity is highly predictable from context (Lieberman 1963, Chafe 1974, Bolinger 1981, Hunnicutt 1985).

The findings mentioned so far do not establish a role of probabilities based on grammatical structure: Lexical frequency, repeated mention in a discourse, and word-to-word cooccurrence probabilities are all based on item-to-item frequencies, without reference to abstract grammatical structure.

A contextual-frequency effect on segment deletion that abstracts away from specific word sequences is discussed by Bybee (2002), who shows that the phonological environments a word occurs in frequently affect the word's readiness to undergo reduction. For example, final segments of words that tend to appear frequently before consonants, an environment that favors lenition and deletion, are more prone to undergo deletion than final segments of words that appear less frequently before consonants. Importantly, this finding does not rest on the frequency of combinations of particular words, but rather on an abstraction to classes of phonological contexts. Viewed in this way, the findings in Bybee 2002 lend motivation to an investigation of probabilistic effects at other abstract levels of linguistic information, including probabilities that are not word-to-word or word-to-sound.

Do probabilities at other levels of abstraction, for example, based on the frequency of particular syntactic patterns, affect pronunciation? Some very tentative evidence comes from a study by Stromswold and colleagues (2002). In the context of a study of comprehension of passive sentences, they noticed that, in their recordings of sentences like *The girl pushed the boy* and *The girl was pushed by the boy*, active verb stems were shorter than passive verb stems. An analysis of a similar set of recordings (Gahl 2002) confirms this observation. Since actives are more frequent than passives, this difference in duration conforms to the generalization that infrequent items are longer than frequent ones. The difference in verb duration, however, may have been due to uncontrolled properties of the recordings in these studies, so effects of constructional frequency on word pronunciation await further investigation in better controlled studies.

It is worth noting that the available information does not conclusively show whether the observed association of high probability and short duration is entirely due to shorten-

ing of high-probability forms, or in part also to lengthening of low-probability ones. Some authors emphasize the former possibility. For example, the general hypothesis investigated by Jurafsky and colleagues is the PHONETIC REDUCTION HYPOTHESIS, which says that 'Words are reduced when they have a higher probability' (Jurafsky et al. 2001:229). Other authors appear to focus on the latter possibility, for example, Bolinger (1963), who hypothesized that speakers would lengthen words that were unusual in a given context. We are not aware of any studies that have directly addressed this question, nor do we directly address it in the current study.

Taken together, the findings of the effects of lexical frequency, contextual predictability, and word-to-word probability suggest that probabilities are capable of affecting pronunciation. Pronunciation variation, specifically durational shortening and segment deletion, may therefore provide a useful diagnostic for effects of probabilities on language production generally. Thus, probabilistic effects at the level of grammatical structure, if they exist, might also manifest themselves as durational shortening and reductive change.

How might durations and /t,d/-deletion serve as diagnostics for a role of probabilities based on syntactic structure? That is the question we turn to next.

3. SUBCATEGORIZATION-BASED PROBABILITIES. What properties must probabilities have before they can be said to make reference to syntactic structure? First, one would certainly ask that the relevant probabilities be based on phrase types, rather than specific lexical items; second, they should make reference to syntactic relationships, rather than simple adjacency or cooccurrence of syntactic phrases; and third, they should be distinguishable from probabilities based on real-world plausibility, that is, the likelihood that a given sentence may be true. Research in sentence comprehension has focused on probabilities that have just these properties and that, we argue, can be manipulated in an analysis of pronunciation to investigate probabilistic effects at the level of grammar.

The probabilities in question are based on the match between VERB BIAS and syntactic context. The BIAS of a verb is the probability with which the verb appears in a given syntactic structure, such as a structure exemplifying a particular subcategorization frame for that verb. In other words, for any given syntactic structure, such as a given type of complementation pattern, a verb's bias toward that structure is a probability, ranging from 0 to 1. When a verb has a high probability of appearing in a given syntactic structure, it is said to have a (high) bias towards that structure. For example, the verb *confirm* is said to have a direct-object bias because most attested uses of that verb involve direct objects (as in *We confirmed the date of our visit*). Verb biases can be estimated based either on corpora or on norming studies using sentence generation or completion tasks. Although these two methodologies do not yield identical results (there are often discrepancies for individual items), they have been shown to correlate strongly and positively (Roland et al. 2000, Lapata et al. 2001, Gahl et al. 2004).

MATCH between verb bias and syntactic structure refers here to the match or mismatch between the bias of a verb and the syntactic context in which it appears. For example, sentences in which the direct-object-bias verb *confirm* in fact has a direct object are said to be BIAS-MATCHING or BIAS-CONFORMING. Sentences in which the verb *confirm* has other types of complements, for example, sentential complements (as in *We confirmed the date was correct*), are said to be BIAS-MISMATCHING or BIAS-VIOLATING. Sentence-comprehension research has shown that, other things being equal, bias-conforming sentences are processed more rapidly and with greater accuracy than bias-violating sentences (Clifton et al. 1984, Ferreira & Henderson 1990, Trueswell et al. 1993, MacDonald 1994, MacDonald et al. 1994, Garnsey et al. 1997, Gahl 2002, Hare

et al. 2003, Wilson & Garnsey 2004). Exactly why this should be the case continues to be a matter of research and debate, but most contemporary models of language processing grant a role to such verb-based probabilities in some manner.

Importantly, verb biases are not based on cooccurrence frequencies of particular words, but on all complements of a given type, regardless of their lexical content. For example, the sentence *We confirmed the caterer ahead of time* contains the verb *confirm* with a direct object. Therefore, it represents a high-probability complementation pattern for this verb, despite the fact that the conditional probability of the words *the caterer* given *confirmed* is smaller than 0.00001, based on counts using a Google internet search. Thus, verb biases satisfy our first desideratum, of referring to syntactic entities rather than to specific lexical items.

The example just cited also illustrates the fact that probabilities based on verb biases satisfy our second desideratum, of making reference to syntactic relationships rather than string adjacency or cooccurrence. A second example may illustrate this point further: Consider the sentence fragment *The director suggested the scene. . . .* The most frequent types of complement of the verb *suggest* are sentential complements, both in corpora and in norming studies (Garnsey et al. 1997, Kennison 1999, Gahl et al. 2004). Therefore, based on verb bias, *the scene* has a high probability of being the subject of a sentential complement, as in *The director suggested the scene should be filmed at night*, and a low probability of being a direct object, as in *The director suggested the scene between Kim and Mike*. It is the status of the noun phrase *the scene* as a direct object, not the frequency with which *suggested* is followed by noun phrases generally, that determines the match between the bias of the verb and the structure of the sentence.

Finally, probabilities based on verb biases satisfy our third desideratum, of being distinguishable from probabilities based on meaning. There is no obvious difference in plausibility between scenarios in which directors put forward scenes involving particular actors and scenarios in which directors propose filming at night, nor is it obvious which of these things happens more often in real life. Determining whether speakers feel that these scenarios differ in plausibility is a matter of careful pretesting of experimental materials. While not all studies of the effects of verb biases have controlled for semantic plausibility or real-world likelihood, some have, showing that plausibility and verb biases are separable factors in sentence comprehension (Trueswell 1996, Garnsey et al. 1997).

The relationship between verb biases and semantic plausibility merits further comment. In some cases, verb biases appear to have a straightforward semantic basis. For example, as Newmeyer (2003) points out, the intransitive bias of the verb *walk* has to do with the fact that people walk themselves on their own accord more often than they, for example, walk dogs. More generally, Keller and colleagues (2002) demonstrate that there is a correlation between certain cooccurrence frequencies of words and human plausibility judgments. The idea that there may be a connection between verb bias and meaning receives indirect support from studies showing that different senses of one and the same verb may be associated with different biases (Roland et al. 2000, Roland 2002, Hare et al. 2003) and from studies showing that verb biases may be related to a verb's syntactic or thematic properties (Stevenson & Merlo 1997). However, the crucial issue in the current context is not whether there is a relationship between verb bias and real-world probability. What is crucial is whether it is possible to tease apart the respective roles of these two factors. That this is in fact possible is suggested by studies that have shown differential effects of bias and plausibility in language processing (see e.g. Trueswell 1996, Garnsey et al. 1997).

Given the evidence for a role of verb biases in comprehension, would we perhaps already be justified in concluding that probabilistic effects at the level of syntax exist? Is there even a need to establish the role of such probabilities in production? Many researchers, ourselves included, have tended to accept the evidence from comprehension as evidence for a role of probabilities in language processing and grammar. As emerges in our discussion, however, there is as yet very little evidence that verb biases affect language production. This raises the possibility that verb biases affect comprehension without affecting speech production. Indeed, such a scenario would be quite plausible: Speakers generally know what they intend to say, whereas listeners have little control over what they will hear. Therefore, predictive guesswork based on probabilities might play a useful role in comprehension without affecting production.

The available evidence for a role of verb biases or syntactic probabilities in language production is quite limited (Jurafsky 2003b). Syntactic priming, that is, speakers' tendency to repeat constituent structures across utterances (Bock 1986, Bock & Loebell 1990), suggests that recent prior exposure to a given syntactic pattern—and hence, perhaps, a pattern's overall frequency in a speaker's experience—plays a role in sentence generation. There is some evidence suggesting that elderly speakers are disproportionately more likely to produce bias-conforming sentences than bias-violating sentences (Almor et al. 2002). Verb subcategorization has been shown to influence word order variation: Speakers are more likely to use heavy NP-shift following verbs like *explain*, which can take sentential complements, than following verbs like *release*, which cannot take sentential complements (Stallings et al. 1998). These findings motivate the expectation that probabilistic information on subcategorization might affect other aspects of language production as well, including form variation.

A small number of previous studies have explored effects of verb biases on pronunciation, so far without finding such effects. Two studies (Speer et al. 1996, Kjelgaard & Speer 1999) examined the acoustic properties of clause boundaries in sentences with early vs. late closure ambiguities, such as *When Roger leaves . . . { the house is dark | the house, it's dark }*. Neither study revealed any significant difference in the pronunciation of such sentences as a function of verb bias. However, the verbs used in these studies were not strongly biased. In addition, the primary focus of these studies was on comprehension, and the phonetic measurements were based on recordings made by a single speaker aiming to produce clear instances of different types of prosodic breaks in the ToBI standard (Silverman et al. 1992). These factors may have been responsible for the absence of a detectable effect. We are not aware of any other studies reporting effects of verb-based or other syntactic probabilities on pronunciation variation.

In sum, if it can be shown that the match between verb bias and syntactic structure affects pronunciation, then this would provide evidence that probabilities based on syntactic information can affect the form of linguistic items. It is the purpose of the present study to provide such evidence.

4. ACOUSTIC PROPERTIES OF SENTENCES WITH DIRECT OBJECT/SENTENTIAL COMPLEMENT AMBIGUITIES. In the preceding sections, we provided motivation for using variations in duration and /t,d/-deletion as diagnostics for effects of probabilities in language production, and we argued that probabilities based on the match between verb bias and sentence structure were based on syntactic structure: If effects of these probabilities on variation in the phonetic realization of words exist, they would establish a role of syntactic probabilities in language production. The direct object/sentential complement (DO/SC) ambiguity (*The director suggested the scene . . .*), in which a noun phrase

is temporarily ambiguous between a direct object (DO) and the subject of a sentential complement (SC), is one of the most thoroughly studied types of temporary ambiguity. Since the processing properties and the acoustic properties of DO/SC sentences are relatively well understood, this ambiguity provides a useful test case for examining the effects of verb biases on pronunciation.

We focus here on the ambiguous portion of DO/SC sentences, starting with the verb and ending with the ambiguous noun phrase. A number of studies (Warren 1985, Beach 1991, Marslen-Wilson et al. 1992, Nagel et al. 1996, Stirling & Wales 1996, Schepman 1997) have examined the acoustic properties of such sentences. All of these studies report that verbs followed by sentential complements are longer than verbs followed by direct objects. For example, Nagel and colleagues (1996) found that the duration of the main verb, measured from its onset to the onset of the following word, that is, including any postverbal pauses, was significantly longer in SC sentences than in DO sentences (669 vs. 393 ms on average). A similar pattern was observed by Schepman (1997), who found average verb durations of 677 ms in SC sentences and 477 ms in DO sentences for the same regions as those examined in Nagel et al. 1996. Similarly, in an investigation of comprehension of DO/SC sentences using synthesized speech, Beach (1991) assigned longer durations to the verbs in SC sentences than in DO sentences (275 vs. 75 ms for the last stressed syllable of the verb). The increased duration of verbs at clause boundaries is consistent with the observation that segmental and word durations are generally increased at major prosodic boundaries and that prosodic boundaries and syntactic phrase boundaries, while not isomorphic, are frequently aligned (Lehiste 1972, Cooper 1976, Lehiste et al. 1976, Price et al. 1991, Steedman 1991, Ferreira 1993, Beckman 1996).

While none of the studies just cited reported the duration of the ambiguous noun phrase, there is reason to believe that noun phrases representing direct objects would be longer than those representing subjects of sentential complements, again on the basis of the location of likely prosodic boundaries. In direct object noun phrases without postmodifiers or further verb arguments or adjuncts, the head noun is the final element not only of the noun phrase, but also of the verb phrase. By contrast, the subject of a sentential complement is not VP-final. There is reason to think, then, that noun phrases representing direct objects in sentences with DO/SC ambiguities might be longer than noun phrases representing subjects of sentential complements.

With this information in hand, we are in a position to formulate our specific hypotheses about the effects of verb biases on pronunciation, specifically, word duration and /t,d/-deletion.

5. HYPOTHESIS AND PREDICTIONS. Our general hypothesis is that words in syntactic structures that have a high probability, given a verb's bias, are more likely to be reduced phonetically than words in low-probability structures. We investigate this hypothesis by examining /t,d/-deletion and the duration of verbs and ambiguous noun phrases in bias-matching and bias-mismatching sentences with DO/SC ambiguities. Our specific hypothesis concerning /t,d/-deletion is as follows:

- (1) Verbs in bias-matching contexts (i.e. contexts that have a high probability, given a verb) will be more likely to undergo /t,d/-deletion than verbs in bias-mismatching (i.e. low-probability) contexts. This means that DO-bias verbs will be more likely to undergo /t,d/-deletion in DO contexts, and SC-bias verbs will be more likely to undergo /t,d/-deletion in SC contexts.

This hypothesis is motivated by the observation that high lexical frequency and high word-to-word probability promote /t,d/-deletion (Gregory et al. 1999, Bybee 2001, Jurafsky et al. 2001).

Our specific hypotheses concerning duration are as follows:

- (2) Bias-violating prosodic boundaries will affect the duration of words and pauses to a greater extent than bias-matching boundaries. Specifically:
 - a. DO-bias verbs and postverbal silences in SC contexts will be longer, compared to their duration in DO contexts, than SC-bias verbs and silences in the same contexts.
 - b. Direct objects of SC-bias verbs will be longer, relative to the duration of the same noun phrases as subjects of sentential complements, than direct objects of DO-bias verbs.

The reasoning that led to our hypotheses concerning duration can be summarized as follows: Previous research has shown that high-frequency and high-probability words tend to be short. By extension, we hypothesized that words and phrases instantiating high-probability syntactic structures would also be short. Sentential complements—and hence, clause boundaries—have a higher probability following SC-bias verbs than following DO-bias verbs, and direct objects have a higher probability following DO-bias verbs than following SC-bias verbs. We reasoned that, in bias-matching contexts, the lengthening typically observed near clause boundaries and phrase-finally might be offset by phonetic reduction found in high-probability items generally. As a result, we hypothesized that the lengthening near prosodic boundaries would be observed to a greater extent in bias-violating contexts than in bias-matching ones.

As noted earlier, it has not been shown whether probability-based variation in duration should be thought of as shortening of high-probability forms, or as lengthening of low-probability ones, or some combination of both. Also as noted earlier, we are in no better position to resolve that question than previous researchers. When we speak of ‘lengthening to a greater or lesser extent’, we do not mean to imply any claim about the direction of change. Our claim is that the match between verb bias and syntactic context affects the degree to which the presence of a prosodic boundary will be reflected in duration of preboundary elements, with bias-violating boundaries being accompanied by greater degrees of lengthening and pausing.

Consider the following examples using the verbs *confirm* and *believe*. Norming studies (Garnsey et al. 1997, Kennison 1999), based on eliciting sentence completions from large groups of speakers, and corpus studies (Gahl et al. 2004) show that *confirm* is far more frequently used with DO complements than with SC complements. Sentences with direct objects therefore represent a higher-probability context for this verb than sentences with sentential complements. The verb *believe*, by contrast, is far more frequently used with SC complements than with DO complements. Therefore, SC contexts represent high-probability contexts for this verb. Table 1 shows examples for the four possible combinations of DO/SC verb bias and DO/SC syntactic context. The hypothesis to be examined here is whether the pronunciation of high-probability sentences like 1 and 4 differs systematically from the pronunciation of low-probability sentences like 2 and 3. Verb tokens that we hypothesized to be particularly prone to undergo /t,d/-deletion are in italics. Words and phrases that we hypothesized to be long are in small caps. We tested these predictions using the materials and methods described in the next sections.

	DO BIAS	SC BIAS
DO SYNTAX	1. The CIA director <i>confirmed</i> the rumor once it had spread widely.	2. The job applicant believed THE INTERVIEWER when she discussed things with her.
SC SYNTAX	3. The CIA director CONFIRMED the rumor should have been stopped sooner.	4. The job applicant <i>believed</i> the interviewer had been dishonest with her.

TABLE 1. High- and low-probability contexts for verbs biased towards DO and SC complements.

6. METHODS.

6.1. PARTICIPANTS. Twenty undergraduate students (ten male, ten female) at the University of Illinois participated in the experiment for payment. All were native speakers of English without hearing problems, based on self-reports.

6.2. MATERIALS AND DESIGN. The sentence materials were a slightly modified subset of those employed in Garnsey et al. 1997 and Wilson & Garnsey 2004. The main consideration in selecting the sentences was strong verb bias, either towards DO or SC. In order to estimate verb biases, Garnsey and colleagues (1997) conducted a norming study in which 108 participants completed sentence fragments consisting of a proper name followed by a verb (e.g. *Debbie remembered* —). For the current study, estimates of verb bias were additionally checked against corpus counts (Gahl et al. 2004). Ten DO-bias verbs and ten SC-bias verbs were selected.

Each of the verbs appeared in two sentences, one containing a direct object (DO) and one containing a sentential complement (SC), for example, *The divorce lawyer argued the issue {was irrelevant to the case/with her colleague across the state}*. The complete set of sentences can be found in the appendix. It was subsequently discovered that one of the SC-bias verbs (the verb *suspect*) was inadvertently used in two different SC sentences, instead of one SC sentence and one DO sentence. We analyzed the results with and without these sentences, with no change in the observed patterns. The results reported here are based on the set of only nineteen verbs, that is, excluding *suspect*.

The two sets of verbs did not differ significantly in frequency or length as measured in numbers of letters, phonemes, or syllables (all $t(1,17) < 1$). The two sets of verbs did differ in DO bias and in SC bias, both based on the sentence-completion data and on the corpus counts (all $p < 0.001$). The properties of the verbs are summarized in Table 2.

	LOG FREQUENCY	LENGTH (LETTERS)	LENGTH (PHONEMES)	LENGTH (SYLLABLES)	DO BIAS (SENTENCE COMPLETION)	DO BIAS (CORPUS COUNTS)	SC BIAS (SENTENCE COMPLETION)	SC BIAS (CORPUS COUNTS)
DO-BIAS VERBS	2.07	8.4	6.9	2.4	0.84	0.83	0.11	0.6
SC-BIAS VERBS	2.01	7.8	6.9	2.3	0.13	0.19	0.55	0.53

TABLE 2. Properties of the verbs.

To ensure that experimental effects of verb bias and syntactic context would not be confounded with effects of the order in which speakers said the sentences, we counterbalanced the presentation order as follows: Each verb was assigned to one of two item groups, such that each item group contained half of the verbs of each type of bias. Two separate presentation lists with forty experimental sentences in two blocks

of twenty sentences were then constructed as follows: On list 1, the verbs in item group 1 appeared in their bias-conforming syntactic context in block 1, and then in their bias-violating context in block 2, while the verbs in item group 2 appeared in their bias-violating syntactic context in block 1, and in their bias-conforming environment in block 2. On list 2, the relative order of bias-conforming and bias-violating environments was reversed. Since the two item groups contained equal numbers of verbs of each bias, this arrangement meant that half of the verbs appeared first in the DO context and the other half occurred first in the SC context. Within blocks, the order of sentences was randomized. The same random order of sentences was used in each block, thus maximizing the distance between sentences containing the same verb. The participants were randomly assigned to two groups, one receiving list 1, the other list 2.

The nouns used in the subject noun phrases for the two sets of verbs did not differ significantly in log frequency ($t(17) < 1, p > 0.10$). There was a marginally significant difference in length (measured as number of syllables) of the subject noun phrases, with subjects of DO-bias verbs being slightly longer than subjects of SC-bias verbs ($t(17) = 2.1, p = 0.06$). We also estimated the plausibility of the subject noun phrases as subjects of the verbs using the methodology described in Keller et al. 2002, based on frequency counts of the beginning portions of our sentences on the web. Keller and colleagues (2002) demonstrate that such counts can reliably predict human plausibility judgments.² A Google search revealed that the two sets of noun phrase + verb combinations did not differ significantly in their frequency, and hence in their estimated plausibility ($t(17) = -0.9, p > 0.10$), based on this method. The subject noun phrases (always *the* plus an adjective-noun or noun-noun combination) and the ambiguous noun phrases (always *the* plus a noun) were different for each verb, but were the same for the two sentences (i.e. the one containing a DO and the one containing an SC) that each verb appeared in. As a referee points out, full lexical noun phrases as subjects are rare in conversation. For example, according to Francis et al. 1999 (see also Givón 1983), full lexical noun phrases account for about 9% of all subject noun phrases. The advantage of using such sentences in the current study lies in our ability to relate the current production results directly to the comprehension research reported in Garnsey et al. 1997 and to other previous psycholinguistic experiments of the DO/SC ambiguity. To our knowledge, these studies have without exception relied on sentences with full lexical subjects.

The plausibility of the ambiguous noun phrases as direct objects of the verbs and as subjects of clauses was assessed in a norming study reported in Garnsey et al. 1997, in which a group of 154 participants rated sentences such as *The senior senator regretted the decision* or *The senior senator regretted the reporter* on a 7-point scale (7 = very plausible). All of the ambiguous noun phrases were highly plausible direct objects of the verbs they appeared with, and the noun phrases used with the two sets of verbs (DO-bias and SC-bias) did not differ significantly in their rated plausibility as direct objects ($t(17) = 1.4, p > 0.10$). They did differ in their rated plausibility as subjects

² The use of web-based data in linguistic research is problematic in some ways, due, for example, to noise, and to the fact that the size of the corpus is unknown and constantly changing. These problems are especially significant when one is consulting the web for information about individual words—the web does not, for example, make a reliable spell checker—or when one is interested in subtle tendencies ('Is this scenario somewhat plausible or somewhat implausible?'). What Keller and colleagues show is that the correlation between human plausibility ratings and web-based data is high enough to ensure that, when one is simply interested in learning whether a particular combination is highly plausible or highly implausible, norming studies and web-based norms are highly likely to yield identical results.

of sentential complements ($t(17) = -2.3, p = 0.03$), as assessed in a separate norming study also reported in Garnsey et al. 1997, in which a group of 52 participants rated sentence fragments such as *The senior senator regretted that the decision was . . .* and *The senior senator regretted that the reporter was. . .* Noun phrases following the SC-bias verbs tended to be rated more plausible as subjects of sentential complements than the noun phrases following the DO-bias verbs. Note that this effect is probably primarily due to verb bias itself: People tend to find ANY noun plausible as the subject of a sentential complement following a verb with a bias toward sentential complements. The postverbal noun phrases used with the two sets of verbs did not differ in log frequency or length in number of letters or syllables (all $p > 0.20$). The properties of the ambiguous noun phrases are summarized in Table 3.

	LOG FREQUENCY	LENGTH (LETTERS)	LENGTH (SYLLABLES)	RATED PLAUSIBILITY AS SUBJECT OF SC	RATED PLAUSIBILITY AS DO
DO-BIAS VERBS	1.91	6.5	2.4	5.81	6.51
SC-BIAS VERBS	1.60	6.8	2.2	6.31	6.15

TABLE 3. Properties of the ambiguous noun phrases.

The portions of the sentences following the postverbal noun phrases, that is, the region that disambiguated the sentences toward a DO or SC structure, also did not differ significantly in length (measured as the number of syllables) for the two sets of verbs (DO-bias and SC-bias; $t(17) < 1$, n.s.). The two sentences each verb appeared in had matching patterns of stressed and unstressed syllables and contained the same number of syllables, except in one case: for the verb *establish*, the DO sentence contained one more syllable than the SC sentence.

The forty experimental sentences were pseudorandomly interleaved with 177 other sentences of various syntactic structures, for a total of 217 sentences. Experimental sentences of identical syntactic structure never appeared in adjacent positions. Sentences containing the same verb were separated by at least 21 sentences.

6.3. PROCEDURE. The sentences were recorded in a sound booth as 16-bit digital sound files at a sampling rate of 44.1 kHz and resampled to 22.1 kHz. The participants were told that the recordings would be used as stimuli in a future experiment. The participants were given the lists of sentences and were encouraged to read each sentence silently first and record it once they were confident they understood what it meant and could say it aloud without difficulty. They were told to try to imagine that they were using the sentences in conversation, as opposed to reading them. The participants were encouraged to repeat sentences on which they misspoke or hesitated. The participants were also told that there was no limit on how much time they could take to read and record the sentences. When speakers misspoke, hesitated, or used a noticeably exaggerated pronunciation after recovering from a garden path ('oh, I get it, . . . The CIA director CONFIRMED the rumor should . . .'), but failed to re-record a sentence, they were asked by the experimenter to repeat the sentence in question. Out of the 760 sentences, 39 were recorded more than once.³ Sentences on which speakers misspoke

³ In the analyses reported here, the final recording of the sentences that elicited multiple attempts were used. The pattern of effects does not change when repeated sentences are excluded from the analysis.

without the experimenter noticing at the time of the recording were subsequently removed from the analysis. For example, subjects sometimes inserted an overt complementizer in SC sentences (e.g. *The film director suggested that the scene should be filmed at night*). A total of six sentences (out of 760) were removed because the experimenter failed to notice that the subject did not say the sentence exactly as written.

All measurements were performed using the Praat phonetics software package and scripting language (Boersma & Weenik 2002) and were based on visual inspection of the waveform and spectrogram, as well as on listening. All durations were measured by a group of three linguistics and psychology undergraduate students at the University of Illinois at Urbana-Champaign and checked by the first author. Instances of deletion of verb-final stops were identified based on inspection of the waveform and spectrogram in conjunction with auditory examination. All measurements and coding were condition-blind.

Duration measurements were taken for the initial subject noun phrase (Subject NP); the silence, if any, following that noun phrase (post-subject silence); the verb (V); the postverbal silence, if any; the ambiguous noun phrase; the silence following the ambiguous noun phrase; and the remaining part of the sentence, that is, the material following the ambiguous noun phrase up to the end of the sentence (End). The duration of each region was measured from the release of the initial stop for words that started with stops, and from the onset of the initial segment for all other words. When the region began with a stop, that stop's closure was included as part of the preceding silence. The rationale for this decision was that it would have been impossible to identify the beginning of the closure portion of a stop in a period of silence. For analogous reasons, we treated the closure of a region-final stop as the endpoint of that region. This means, for example, that the postverbal silence includes the closure portion of any verb-final stops.

All measures were submitted to repeated measures analyses of variance (ANOVA) with speakers (F1) and verbs (F2) as random factors and List (randomly assigned presentation list 1 or 2), Itemgroup (randomly assigned verb group 1 or 2), Bias (DO or SC), and Match (bias-matching or bias-violating) as factors. Nonsignificant effects that were of no theoretical interest are not reported here. The /t,d/-deletion measures were then analyzed further in a logistic regression analysis. Effects are reported as significant when at or below the 0.05 level of significance.

7. RESULTS.

7.1. ANALYSIS OF /t,d/-DELETION RATES. Figure 1 shows the proportion of verb-final stops that were deleted in each of the four sentence types (DO and SC, for sentences containing DO-bias and SC-bias verbs, respectively). Our hypothesis was that the rate of /t,d/-deletion would be higher in the conditions where sentence type and verb bias matched (i.e. DO sentences for DO-bias verbs, and SC sentences for SC-bias verbs) than in the conditions where they did not match. The results were consistent with this hypothesis.

An ANOVA revealed that there was a significant effect of Match in the predicted direction: The proportion of tokens with /t,d/-deletion was higher in the 'matching' conditions than in the 'mismatching' conditions ($F1(1,19) = 11.0, p < 0.01$; $F2(1,18) = 8.7, p < 0.01$). The rate of /t,d/-deletion did not differ across verb types (Bias) or across sentence types (Syntax), producing no significant interaction of Bias by Match (all $F_s < 1$). In summary, the results of the analysis of variance were consistent with our hypothesis that /t,d/-deletion rates would be higher in sentences with matching verb bias and syntactic structure than in sentences with mismatched verb bias and structure.

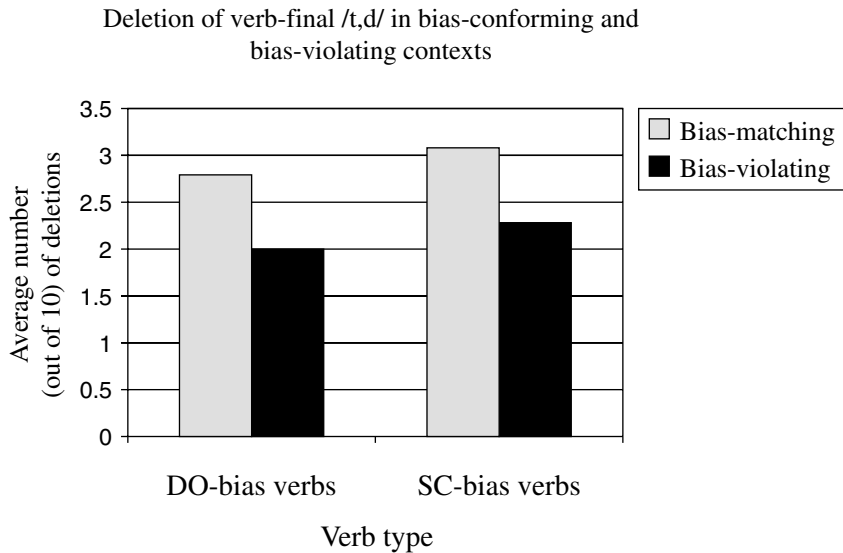


FIGURE 1. Proportion of verb tokens with /t,d/-deletion.^a

^a Bias-matching syntactic contexts contain direct objects (DO) for DO-bias verbs and sentential complements (SC) for SC-bias verbs. Bias-violating syntactic contexts contain sentential complements for DO-bias verbs and direct objects for SC-bias verbs.

However, the ANOVA fails to take into account factors that are known to affect /t, d/-deletion, but that were not factorially manipulated in the experiment. To determine whether the match between verb bias and sentence type made a significant contribution beyond previously studied factors, we performed a logistic regression analysis.

A logistic regression analysis is a statistical model that relates one or more predictor variables to a categorical dependent variable—in our case, the deletion of a verb-final stop. In a model with multiple predictor variables, a predictor variable is said to have a significant effect when its inclusion in the model yields a significantly better account of the variation in the dependent variable, after accounting for the effects of the other predictor variables. Along with the significance levels, we report the odds ratio (OR) associated with each predictor variable, which denotes the change in the odds of a verb token undergoing /t,d/-deletion for a one-unit increase in a predictor variable. An odds ratio greater than 1 indicates that the odds of /t,d/-deletion increase as the values of the predictor variable increase. An odds ratio smaller than 1 indicates that the odds decrease as the value of the predictor variable increases.

We controlled for the effect of factors already known to affect /t,d/-deletion, and also of presentation list and ‘block’ (i.e. whether a verb token represented the first or second time a speaker said a given verb in the experiment), by entering them first in the regression model. The baseline model for the analysis was a regression including the following eight control factors, which have been found to affect /t,d/-deletion in previous studies, or which encoded particulars of our experimental design that might potentially have affected /t,d/-deletion: (i) log frequency of the verb; (ii) sex of the speaker; (iii) inflectional regularity (coded here as a categorical variable with three levels: 1 for the stem-alternating forms *wrote* and *understood*, 2 for the ‘doubly-marked’ (stem-alternating and suffixed) *heard*, and 3 for all regular verbs, that is, all other verbs in our sample); (iv) manner of articulation of the preceding consonant (coded as a

categorical variable with four levels: 1 for vowel, 2 for liquids and non-sibilant fricatives, 3 for nasal and oral stops, 4 for sibilants); (v) place of articulation of the preceding consonant; since all verbs in our materials were immediately followed by a definite article, and since /t,d/-deletion has been found to be most frequent between homorganic consonants (Guy 1980, Neu 1980), we coded this as a binary variable distinguishing alveolar from all other consonants; (vi) speaking rate, calculated as the number of syllables in each sentence, divided by the duration of the sentence; (vii) presentation list (as noted earlier, verb bias and syntactic structure were counterbalanced in the two lists); and (viii) block, that is, whether a verb token represented the first or the second time a given speaker had encountered this verb in the experiment.

7.2. RESULTS OF LOGISTIC REGRESSION ANALYSIS. Consistent with previous studies, most previously studied factors were significant predictors of /t,d/-deletion in our data. Log frequency of the verb was only a marginally significant predictor in the baseline model (OR = 1.66, $p = 0.07$), probably due to the fact that all of the verbs we used were fairly common, limiting the range of values in this variable. Speaking rate was not a significant predictor of deletion in the baseline model ($p > 0.10$), perhaps due to the fact that speaking rate also did not vary much across sentences since our sample was based on read speech. Inflectional regularity was a significant predictor, although not in the direction normally observed, since greater deletion rates were associated with regular than with stem-alternating verbs (OR = 7.71, $p < 0.01$). This is likely due to the fact that all but three verbs in our sample were regular. All other previously known factors were significant predictors, in the manner one would expect based on earlier studies: Male speakers were more likely than female speakers to apply deletion (OR = 1.81, $p < 0.01$). Place and manner of the preceding segment were significant predictors as well, in the direction observed in previous studies, with homorganic sibilants maximally promoting /t,d/-deletion (OR = 0.171, $p < 0.001$ for Place; OR = 1.77 for Manner, $p < 0.001$). Presentation list was not a significant predictor, meaning that there was no difference between speakers who saw list 1 vs. list 2 ($p > 0.10$). Interestingly, Block was also not a significant predictor, meaning that whether a speaker was saying a verb for the first time or the second time within the experiment did not significantly affect the likelihood of /t,d/-deletion ($p > 0.10$).

The variable of interest in the current study was the match between verb bias and syntactic structure. When added to the baseline model, this factor was a significant predictor (OR = 1.7, $p < 0.01$), in the hypothesized manner: Verb tokens in bias-matching sentences were more likely to undergo /t,d/-deletion than verb tokens in bias-violating contexts. The pattern of significance of the control factors remained unchanged when match was added, except for the fact that speaking rate approached marginal significance in this model (OR = 1.3, $p = 0.097$).

To probe the source of these effects further, we examined the effect of the strength of the DO or SC bias. The verbs in our set can take other complement types besides DO or SC. For example, the DO-bias verb *hear* can also take PP complements, as in *Did you hear about the rehearsal?*. Although all of our DO-bias verbs were most likely to take DO complements, they did not all have an equally low probability of taking SC complements. The same holds, *mutatis mutandis*, for the SC-bias verbs. If the match between verb bias and sentence structure affects /t,d/-deletion, then we should expect the strength of a verb's DO bias to be a better predictor of deletion in DO sentences than its SC bias. Conversely, we should expect SC bias to be a better predictor in SC

sentences than DO bias. Separate analyses of DO and SC sentences confirmed this expectation: In DO sentences, DO bias was a significant predictor of /t,d/-deletion ($OR = 5.09, p < 0.05$), but SC bias was not ($p > 0.10$). By contrast, in SC sentences, SC bias was a marginally significant predictor ($OR = 6.6, p = 0.06$), but DO bias was not ($p > 0.10$). The power to identify significant predictors depends in part on the size of the dataset. Since there are only half as many data points in the separate analyses for DO and SC sentences, the failure of DO bias to reach significance in the analysis of SC sentences cannot be taken to mean that DO biases have no effect on the behavior of verbs in SC sentences, and vice versa. However, the fact that a verb's bias towards a given structure was a better predictor than its bias towards a different structure lends further support to our hypothesis that it is a verb's bias towards a given structure that affects /t,d/-deletion rates in that structure.

In summary, the results of the logistic regression analysis of /t,d/-deletion were consistent with our hypothesis: Verbs were more likely to undergo /t,d/-deletion in high-probability syntactic contexts than in low-probability syntactic contexts.

8. ANALYSIS OF DURATIONS. We now turn to the analysis of durations. The results of the duration measurements are summarized in Figure 2, collapsing across lists and item groups.

8.1. DURATION OF VERBS. Our specific hypothesis about the duration of the verbs was that DO-bias verbs in SC contexts ([*confirmed*] *the rumor should . . .*) would be lengthened to a greater extent, compared to DO contexts ([*confirmed*] *the rumor, once . . .*), than SC-bias verbs in SC contexts ([*believed*] *the interviewer had . . .*) compared to DO contexts ([*believed*] *the interviewer when . . .*). The results of the ANOVA were consistent with this hypothesis: There was a significant interaction of Bias by Match ($F(1,19) = 7.1, p < 0.02$; $F(1,17) = 6.5, p < 0.05$). Partitioned analyses for the two types of bias revealed an effect of Match for the DO-bias verbs in the predicted direction: DO-bias verbs were significantly longer before clause boundaries (433 ms) than before direct objects (421 ms). This effect was marginally significant in the analysis by subjects, and significant in the analysis by items ($F(1,19) = 4.0, p = 0.06$; $F(1,9) = 5.7, p < 0.05$). By contrast, the duration of SC-bias verbs in matching (402 ms) vs. mismatching (396 ms) contexts did not differ significantly ($F(1,19) < 1.5, F(1,8) < 2, n.s.$).

8.2. DURATION OF SILENCES FOLLOWING THE VERB. For the postverbal silences, the Bias \times Match interaction reached only marginal significance ($F(1,19) = 4.0, p = 0.06$; $F(1,17) = 3.7, p = 0.07$). There was a significant main effect of Match ($F(1,19) = 9.2, p < 0.01$; $F(1,17) = 10.2, p < 0.01$), reflecting the fact that postverbal silences in bias-violating sentences were longer than silences in bias-matching sentences, regardless of sentence type. It should be noted that the closure portion of verb-final stops was included in our measurements of the postverbal silence; thus, the observed main effect of Match on the duration of the postverbal silence is in part a consequence of the greater rate of /t,d/-deletion in bias-matching contexts. Duration of the postverbal silence and /t,d/-deletion are not completely independent measures.

In order to explore our specific hypothesis about postverbal silences, according to which the presence of a clause boundary would affect the duration of silences following DO-bias verbs more than silences following SC-bias verbs, we carried out partitioned analyses for each type of bias, despite the only marginal significance of the Bias \times Match interaction. There was a significant effect of Match for DO-bias verbs (33 vs.

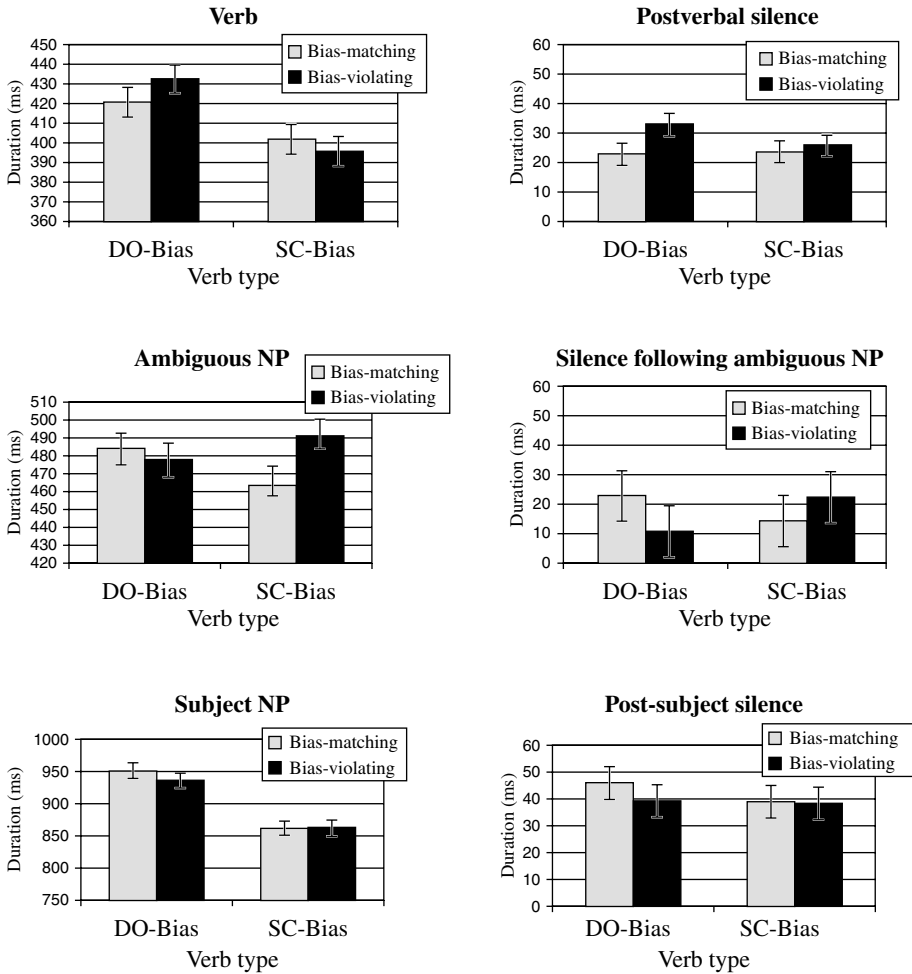


FIGURE 2. Average duration (in milliseconds) of six regions of bias-matching and bias-violating sentences with DO-bias and SC-bias verbs.^a

^a The error bars represent 95% confidence intervals around the means of each condition, calculated as recommended by Loftus and Masson (1994) for mixed within- and between-groups designs like the one used in our study.

23 ms) but not for SC-bias verbs (23 vs. 26 ms) (DO-bias: $F(1,19) = 13.1, p < 0.01$; $F(2,19) = 10.4, p < 0.02$; SC-bias: $F(1,19) < 1, F(2,18) < 1.5, n.s.$). Thus, the silences following DO-bias verbs were longer in SC contexts than in DO contexts, whereas the silences following SC-bias verbs were not significantly affected by sentence type. This pattern is consistent with our hypothesis.

8.3. DURATION OF AMBIGUOUS NOUN PHRASES. Our specific hypothesis about the ambiguous noun phrases was that direct objects of SC-bias verbs (*believed [the interviewer] when . . .*) would be longer, relative to their duration as subjects of sentential complements (*believed [the interviewer] had . . .*), than direct objects of DO-bias verbs (*confirmed [the rumor], once . . . vs. confirmed [the rumor] had . . .*). Put differently, we predicted that the status of a noun phrase as a direct object would have a greater

effect in sentences with SC-bias verbs than in sentences with DO-bias verbs. The Bias \times Match interaction was significant in the analysis by subjects, and marginally so in the analysis by items ($F1(1,19) = 13.6, p < 0.01$; $F2(1,17) = 4.2, p = 0.06$). Partitioned analyses for each type of bias revealed that, consistent with our hypothesis, noun phrases following SC-bias verbs were significantly longer when they represented direct objects (491 ms) than when they represented subjects of sentential complements (463 ms: $F1(1,19) = 25.1, p < 0.001$; $F2(1,8) = 9.2, p < 0.02$). By contrast, there was no significant effect of Match on the duration of noun phrases following DO-bias verbs (484 vs. 477 ms: $F1(1,19) < 1.5, F2(1,9) < 1, n.s.$).

8.4. DURATION OF SILENCES FOLLOWING THE AMBIGUOUS NOUN PHRASES. For the silence, if any, following the ambiguous noun phrase, the Bias \times Match interaction was significant in the analysis by subjects, but not by items ($F1(1,19) = 6.4, p < 0.05$; $F2(1,17) = 3.1, p = 0.10$). To explore the variation further, we performed separate analyses for the two types of bias. For the DO-bias verbs, the analysis by subjects revealed a significant effect of Match (23 vs. 11 ms), which did not, however, approach significance in the analysis by items ($F1(1,19) = 6.1, p < 0.05$; $F2(1,9) < 2, n.s.$). For the SC-bias verbs, there was no significant effect of Match (23 vs. 14 ms: $F1(1,19), F2(1,8) < 2$), contrary to our hypothesis.

It is interesting to note that the post-NP2 silences tended to be long when the phrases were short and vice versa. This pattern is characteristic of items within prosodic domains, as opposed to items at domain edges (Ferreira 1993), which suggests that speakers tended not to produce prosodic breaks immediately following the ambiguous noun phrase. As noted above, the direct object noun phrases in our materials were heterogeneous in structure, with some nouns constituting the final element of their phrases (e.g. *confirmed [the rumor]_{NP} once it had spread . . .*) and others being followed by postmodifiers within the same phrase (e.g. *heard [the story]_N of how the five others had left]_{NP}*). To explore the extent to which this heterogeneity affected the results, we performed separate analyses for the phrases with phrase-final vs. phrase-medial head nouns, which did not reveal any significant effects: There was no significant difference in the duration of head-final vs. head-medial phrases, and no significant effect of Match on the duration of either head-final ($n = 5$) or head-medial ($n = 4$) direct objects of SC-bias verbs. Given the small number of items in the partitioned analyses, the absence of an effect of head-position is not surprising. Yet, the structural heterogeneity of the object noun phrases may have been responsible for the absence of a significant effect in the analysis by items.

8.5. DURATION OF SUBJECT NOUN PHRASES. We had no specific hypothesis concerning the duration of the sentence-initial noun phrases. We nevertheless analyzed the duration of these phrases, in order to explore whether initial noun phrases in bias-violating sentences were lengthened generally: Speaking rates tend to slow in parts of sentences preceding words or phrases that are difficult to produce (Arnold et al. 2003). Therefore, lengthening of initial noun phrases in bias-violating sentences would point to difficulties in retrieval or production of bias-violating sentences as a source of the observed variation. The pattern of durations of the initial noun phrases did not support an explanation along these lines: Initial noun phrases were longer in bias-matching DO sentences (*[The CIA director] confirmed the rumor once . . .*) than in any other sentence type, and longer in bias-matching SC sentences (*[The job applicant] believed the interviewer had . . .*) than in bias-violating SC sentences (*[The CIA director] confirmed the rumor should . . .*), producing a Bias \times Match interaction that was significant in the analysis

by items, but not by subjects ($F1(1,19) < 2.5$, n.s.; $F2(1,17) = 6.4$, $p < 0.05$), as well as a significant simple effect of Match in sentences with DO-bias verbs ($F1(1,19) = 6.1$, $p < 0.05$; $F2(1,9) = 11.2$, $p < 0.01$), but not in sentences with SC-bias verbs ($F1(1,19)$, $F2(1,8) < 1$, n.s.). In sum, the pattern of results in the initial noun phrases is not what one would expect if the effect of Match on durations straightforwardly resulted from production difficulties with bias-violating sentences.

8.6. EFFECTS OF REPETITION. To investigate the possible role of articulatory practice in the observed variation, we also examined the effect of repetition in our experiment. Since our materials contained pairs of partially identical sentences, such as *The divorce lawyer argued the issue . . .*, we were able to compare the durations of the two occurrences of each ambiguous fragment.

The average durations of the first and second tokens in each sentence region are shown in Table 4. As one would expect based on previous studies of repetition (Fowler & Housum 1987, Bard et al. 2000), speakers had a tendency to shorten noun phrases they had said previously. Paired *t*-tests confirmed that this tendency was significant for the initial noun phrase (922 vs. 896 ms: $t1(1,19) = 3.3$, $p < 0.01$; $t2(1,18) = 5.582$, $p < 0.001$) and the silence following it (44 vs. 37 ms: $t1(1,19) = 2.2$, $p < 0.5$; $t2(1,18) = 2.1$, $p < 0.001$), as well as for the ambiguous noun phrase (485 vs. 472 ms: $t1(1,19) = 2.4$, $p < 0.05$; $t2(1,18) = 2.6$, $p < 0.02$) and the silence following that noun phrase (22 vs. 14 ms: $t1(1,19) = 2.3$, $p < 0.05$; $t2(1,18) = 2.1$, $p = 0.05$).

	FIRST OCCURRENCE	SECOND OCCURRENCE
Subject NP	922	896
Sil 0	44	37
Verb	414	413
Sil 1	27	25
Ambiguous NP	485	472
Sil 2	22	14

TABLE 4. Average durations (in milliseconds) of six regions of DO/SC sentences, comparing first vs. second occurrences.

Unlike repeated noun phrases, repeated verbs and postverbal silences did not get shortened significantly (414 vs. 413 ms for the verb: $t1(1,19) = 0.3$, $p > 0.10$; $t2(1,18) = 0.5$, $p > 0.10$; 27 vs. 25 ms for the postverbal silence: $t1(1,19) = 1.8$, $p = 0.09$; $t2(1,18) = 1.6$, $p > 0.10$). This result suggests that the shortening of repeated items is not simply due to increased articulatory fluency, casting some doubt on explanations of frequency-based changes as purely due to more highly practiced articulatory routine.

8.7. SUMMARY OF DURATION RESULTS. In summary, the duration measurements, like the distribution of /t,d/-deletion, were consistent with our hypothesis: In DO contexts, direct objects of SC-bias verbs were longer than direct objects of DO-bias verbs, while in SC contexts, DO-bias verbs and the silences following them were longer than SC-bias verbs and silences. The observed durations of the initial subject noun phrase do not suggest that lexical-retrieval or sentence-planning difficulties are the source of the observed variation.

9. DISCUSSION. Our central result was that the contextual probability of a syntactic pattern, given a particular verb, affected the pronunciation of words in those structures. The distribution of /t,d/-deletion and the duration measurements bore out our specific predictions: (i) verbs were more likely to undergo /t,d/-deletion in high-probability

syntactic contexts than in low-probability contexts; (ii) clause boundaries that had a low probability, given a verb's bias, affected verb and pause durations to a greater extent than did clause boundaries that had a high probability; and (iii) noun phrases representing low-probability direct objects were longer than noun phrases representing high-probability direct objects. Since the high-probability sentences were judged to be no more likely to be true in the real world than the low-probability sentences, these results suggest that the contextual probability of syntactic structures affects variation in the phonetic realization of words in those structures, independently of meaning.

Previous explanations of probabilistic effects on pronunciation have appealed to three types of mechanisms: articulatory fluency, retrieval difficulties, and speaker-controlled variation. We discuss the extent to which each of these explanations might account for the patterns we observed. We then argue that the observed variation in pronunciation reveals effects of probabilities at the level of syntactic structure, consistent with the notion that knowledge of syntactic probabilities is part and parcel of syntactic knowledge.

9.1. ARTICULATORY PRACTICE AS A SOURCE OF SHORTENING. One possible source of durational shortening and segment deletion in high-frequency expressions lies in practice effects on articulatory fluency. For example, Bybee and Hopper (2001a:11) assert that '[t]he origins of reduction are in the automatization of neuro-motor sequences which comes about through repetition'. Bybee and Hopper do not advocate articulatory fluency as the only mechanism underlying shortening effects, however, adding that 'reduction or lack of reduction are carefully monitored and controlled by the speaker according to the context'. One difficulty with articulatory fluency as the sole basis for an explanation of the effects reported here is that a given sequence, such as *We confirmed the caterer*, may represent a high probability structure without ever having been articulated or encountered before. Articulatory practice does not constitute a likely explanation of our results, since the relevant probabilities are not associated with particular words or stretches of speech that could be practiced.

Further evidence against articulatory fluency as the source of the effect comes from our observations about the effect of repetition within the experimental sessions. If reductive change in high-frequency and high-probability expressions were entirely due to increased articulatory routine, then we should expect simple repetition (which increases articulatory routine) to induce shortening as well. We did in fact observe an effect of repetition in our data: Each participant said the ambiguous portion of our experimental sentences twice, once with a bias-matching continuation, and once with a bias-violating continuation. As one might expect, phrase durations were shorter for the second token of each ambiguous region. However, repetition led only to shortening of noun phrases in this way; there was no shortening effect on verbs. If shortening of high-probability forms were due to articulatory practice effects, similar to shortening of repeated words, then we would expect it to apply to noun phrases and verb phrases alike.⁴

The fact that repetition affected only noun phrases, not verbs, deserves further investigation. To our knowledge, a differential effect of repetition on verb duration vs. noun

⁴ A referee points out that the repeated verb tokens were used in different constructions (DO and SC) and raises the possibility that it could be the repetition of the whole construction (the NP or the V and its complements) that leads to shortening. However, since the repetition effect did hold for the ambiguous noun phrases, which also appeared in two different syntactic contexts (as direct object or subject of sentential complement), this factor does not explain why we did not observe an effect of repetition on verbs.

duration has not been reported before. Also of note is the fact that even for noun phrases, the shortening of repeated items may not have been entirely due to simple repetition. One participant commented after the experiment that he suspected we planned to assemble the recorded sentences into stories. When asked why he thought this, he explained that he recognized different 'characters' that were mentioned several times, such as *the cook*, *the divorce lawyer*, *the judge*, and so on. This suggests that the shortening of second occurrences of noun phrases in our experiment may have in part reflected an effect of givenness (Fowler & Housum 1987, Bard et al. 2000) in an imagined discourse, rather than simple repetition.

9.2. RETRIEVAL AND PRODUCTION DIFFICULTIES AS A SOURCE OF LENGTHENING. Lexical-retrieval difficulties constitute a second possible source of probability-based form variation. Low-frequency words are named and produced more slowly, a fact that has been attributed to difficulties in lexical access and retrieval, as well as to motor fluency (Balota & Chumbley 1985). Could retrieval difficulties have been responsible for the observed increased durations of words in low-probability contexts? It is certainly the case that high-frequency words and frequently used multiword expressions are accessed faster. Moreover, any factor that increases language-processing demands tends to slow down lexical retrieval. Studies of the comprehension of low-probability sentences strongly suggest that such sentences induce increased processing demands in comprehension. Therefore, it is conceivable that, in production as well as in comprehension, retrieval of words in low-probability contexts is slowed. The effects reported here do not easily yield to an explanation along these lines, however: retrieval difficulties in connected speech are associated with slowed speaking rates not only on the inaccessible word, but also in the phrases leading up to the problematic item. If retrieval difficulties were the source of the results reported here, we should expect lengthening of phrases preceding words in low-probability contexts, such as subject noun phrases in bias-violating sentences, or DO-bias verbs in SC contexts. Our results do not bear out this expectation, casting some doubt on retrieval difficulties as the source of the effect. Language production, however, is a highly demanding process that requires coordinating many different steps, including planning what meaning one wishes to convey, lexical access and retrieval, as well as assembly of syntactic form, monitoring for errors, possibly taking into account the reactions of an interlocutor, and so on. Since we asked speakers to read the sentences silently first before recording them, the words they used in making the recordings were already primed, that is, pre-activated. Moreover, the reading-aloud task meant that speakers were relieved of the task of thinking of what to say and were not interacting with any interlocutor or carrying out normal communicative tasks. Therefore, the reading-aloud task employed here is not well-suited for an investigation of retrieval difficulties. We utilized read speech in our experiment and encouraged the speakers to read each sentence silently first and only record it once they were confident they could say it without difficulty. This decision was prompted by the need to exert careful control over word choice and the desire to avoid speakers' being taken by surprise while reading bias-violating sentences. There is certainly a need to explore the effects described here in more naturalistic settings. It is conceivable that retrieval difficulties might affect the production of bias-violating sentences in spontaneous speech.

9.3. SPEAKER-CONTROLLED FACTORS AS A SOURCE OF PROBABILISTIC PRONUNCIATION VARIATION. If articulatory fluency or lexical-retrieval difficulties are not the source of

the patterns we observed, then what is? A consideration of speaker-controlled variation offers a promising approach. It has been proposed, for example, that speakers lengthen words that are unusual in a given context, perhaps because listeners need to be able to hear words more clearly when strong contextual clues are absent (Bolinger 1963, 1981). A similar idea forms part of the hyper- and hypospeech theory (H&H theory) of Lindblom (1990). The central idea in this theory is that speakers choose to exert greater or lesser articulatory effort, generally minimizing articulatory effort, but taking into account factors that might affect intelligibility. Highly predictable forms, on this view, tend to be produced with less articulatory effort and shorter durations. Our results might lend themselves to an explanation along these lines: Verbs in low-probability contexts, given the verb's bias, were less prone to /t,d/-deletion, perhaps reflecting clearer articulation. Similarly, prosodic boundaries that a listener could not 'expect', given a verb's bias, were associated with stronger durational cues in our data.

There are, however, a number of complicating factors that need to be investigated further before we can fully understand the source of the effect. The fact that speakers do not consistently seem to modify their speech based on listeners' perceived needs (Ferreira & Dell 2000) in sentences very much like those used here is one such complication.

10. CONCLUSION. As we argued in the introductory sections in this article, previous research arguing for a role for probabilities at the level of grammar is vulnerable to two objections. First, frequency of usage is in part a function of meaning and real-world likelihood; therefore, some effects of frequencies and probabilities may be due to the frequency or probability of particular real-life scenarios. Different pronunciations of one and the same word may be identical in meaning; therefore research on pronunciation variation has a potentially important role to play in meeting this first objection. However, previous research on probabilistic pronunciation variation, based on sound-to-sound or word-to-word transitional probabilities, is vulnerable to a second objection: Grammars of natural languages cannot be described in terms of transitional probabilities, but must allow reference to abstract categories and syntactic relationships between them (Chomsky 1957). How do the results reported here withstand these two objections?

The first objection, we argued, can be met—and has been met by previous authors—through careful pretesting of experimental materials. In pretest norming, the DO and SC continuations in our sentences were judged to be equally plausible with either verb type. Therefore, the observed effects are unlikely to stem from any difference in perceived real-world likelihood or plausibility.

A second limitation of previous research on probabilistic pronunciation variation is that variation reflecting sound-to-sound or word-to-word probabilities cannot be said to reflect probabilities at the level of grammar, if it is assumed that the grammars of natural languages are not adequately captured by such surface string probabilities. The probabilities considered here are based on verb complementation patterns independently of the words instantiating those patterns. Since we manipulated the contextual probability of syntactic patterns, keeping the words in those patterns constant, the observed effect cannot simply be based on word-to-word probabilities. What we have shown is that there are systematic differences in pronunciation reflecting the probability of a given syntactic structure in a given context. Thus, pronunciation variation reflects contextual probabilities of syntactic structures, not just information about which words are likely to be adjacent to each other.

One question raised by our findings concerns how knowledge of probabilities and of probabilistic form variation might be represented. We are not in a position to resolve

this question on the basis of our experimental results. We note that probabilistic models of syntax (e.g. Manning 2003) offer a straightforward way for probabilities to be represented in syntax. We also note that our results can most readily be accommodated by models of speakers' knowledge of linguistic form that include very fine-grained phonetic variation (cf., for example, the 'exemplar-based' models of Johnson 1997, Pierrehumbert 2001), particularly if it can be shown that listeners are able to use information on, for example, subtle variations in duration to infer whether they are listening to sentences whose syntactic structures have a low contextual probability. We are currently conducting further experiments to determine whether this is the case. Since our results are not based on the probability of specific sequences of words that could be stored as complex exemplars, however, the nature of speakers' representations of the pronunciation variants remains unclear.

Our finding that pronunciation variation reveals effects of probabilities at the level of syntax is consistent with the view that language production and comprehension is shaped by speakers' exposure to language. It is further consistent with the view that 'the way language is used affects the way it is represented cognitively' (Bybee 2001:5). The findings reported here are based on probabilities based on grammatical information, consistent with the notion that knowledge of probabilities forms an integral part of grammatical knowledge. Indeed, we believe that grammatical knowledge is highly malleable and very sensitively tuned to frequencies and probabilities in speakers' experience. This belief is consistent with other recent findings showing the constant malleability of the adult language system (see e.g. Onishi et al. 2002).

What we have shown is that probabilities making crucial reference to syntactic information affect the form of linguistic items. We believe that the most parsimonious accounts of these effects will be ones in which the grammar itself is enriched with probabilistic information.

APPENDIX: SENTENCE MATERIALS USED

DO-BIAS ITEMS

VERB	DO BIAS (GPML) ⁵	DO BIAS (GJR)	SC BIAS (GPML)	SC BIAS (GJR)	SENTENCES
accept	0.97	0.94	0.02	0.00	The talented photographer accepted the money with much reluctance. The talented photographer accepted the money could not be spent yet.
advocate	0.87	0.89	0.05	0.05	The newspaper editor advocated the truth publicly and with great zeal. The newspaper editor advocated the truth needed to be made public.
confirm	0.74	0.89	0.26	0.09	The CIA director confirmed the rumor once it had spread widely. The CIA director confirmed the rumor should have been stopped sooner.
emphasize	0.79	0.88	0.18	0.11	The angry father emphasized the problems faced by those who lived far away. The angry father emphasized the problems were continuing to get worse.

(continued)

⁵ GPML refers to Garnsey et al. 1997; GJR refers to Gahl et al. 2004.

APPENDIX: (CONTINUED)

DO-BIAS ITEMS

VERB	DO BIAS (GPML)	DO BIAS (GJR)	SC BIAS (GPML)	SC BIAS (GJR)	SENTENCES
establish	0.94	0.98	0.06	0.01	The primary suspect established the alibi with the help of an old spy. The primary suspect established the alibi had been a total lie.
hear	0.76	0.59	0.16	0.08	The gossipy neighbor heard the story of how the five others had left. The gossipy neighbor heard the story had never actually been true.
maintain	0.74	0.84	0.23	0.13	The confident engineer maintained the machinery of the whole upper deck. The confident engineer maintained the machinery would be hard to destroy.
print	0.77	1.00	0.01	0.00	The journal editor printed the article with the footnotes at the end. The journal editor printed the article had been slanderous to him.
understand	0.91	0.77	0.09	0.10	The frustrated tourists understood the message when it had been explained. The frustrated tourists understood the message would mean they couldn't go.
write	0.90	0.52	0.00	0.06	The art critic wrote the interview with little regard for readers. The art critic wrote the interview had been a complete disaster.
MEAN	0.839	0.83	0.106	0.063	

SC-BIAS ITEMS

VERB	DO BIAS (GPML)	DO BIAS (GJR)	SC BIAS (GPML)	SC BIAS (GJR)	SENTENCES
argue	0.11	0.04	0.35	0.61	The divorce lawyer argued the issue was irrelevant to the case. The divorce lawyer argued the issue with her colleague across the state.
believe	0.14	0.06	0.50	0.73	The job applicant believed the interviewer had been dishonest with her. The job applicant believed the interviewer when she discussed things with her.
claim	0.06	0.38	0.68	0.42	The weary traveler claimed the luggage had been stolen in Rome. The weary traveler claimed the luggage at the counter in Prague.
concluded	0.14	n/a	0.81	n/a	The account executive concluded the speech had not gone very well. The account executive concluded the speech with a joke about style.
confess	0.20	0.22	0.49	0.33	The bank guard confessed the robbery had been his own idea. The bank guard confessed the robbery after a sleepless night.

(continued)

APPENDIX: (CONTINUED)

SC-BIAS ITEMS

VERB	DO BIAS (GPML)	DO BIAS (GJR)	SC BIAS (GPML)	SC BIAS (GJR)	SENTENCES
decide	0.02	0.05	0.15	0.33	The experienced judge decided the appeal should be started right away. The experienced judge decided the appeal on the merit of the case.
figure	0.07	0.26	0.48	0.54	The shrewd salesman figured the prices would be going up soon. The shrewd salesman figured the prices for the recent book sale.
realize	0.19	0.20	0.80	0.74	The novice plumber realized the mistake would cost someone some money. The novice plumber realized the mistake before calling the owner.
suggest	0.21	0.32	0.73	0.50	The film director suggested the scene should be filmed at night. The film director suggested the scene between Bonnie and Clyde.
suspect	0.30	0.39	0.68	0.49	The high-school principal suspected the teenager wasn't telling the truth. The high-school principal suspected the teenager sometimes cheated in class.
MEAN	0.158	0.244	0.568	0.52	

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