Cognitive Science 26 (2002) 737–766
COGNITIVE SCIENCE
http://www.elsevier.com/locate/cogsci

Overtensing and the effect of regularity

Joseph Paul Stemberger*

Department of Linguistics, University of British Columbia, E270-1866 Main Mall, Vancouver, BC, Canada V6T 1Z1

Received 20 November 2001; received in revised form 24 June 2002; accepted 17 July 2002

Abstract

Regularly inflected forms often behave differently in language production than irregular forms. These differences are often used to argue that irregular forms are listed in the lexicon but regular forms are produced by rule. Using an experimental speech production task with adults, it is shown that overtensing errors, where a tensed verb is used in place of an infinitive, predominantly involve irregular forms, but that the differences may be due to phonological confounds, not to regularity *per se*. Errors involve vowel-changing irregular forms more than suffixing inflected forms, with at best a small difference between regular *-ed* and irregular *-en*. Frequency effects on overtensing errors require a model in which the past-tense and base forms of the verb are in competition and in which activation functions are nonlinear, and rule out models with specialized subnetworks for past-tense forms. Implications for theories of language production are discussed.

Keywords: Morphology; Language production; Errors; Dual-mechanism models; Past tense; Activation functions

1. Introduction

In language, as in many cognitive domains, there is a great deal of regularity. For example, most past-tense forms of verbs in English are produced with an *-ed* at the end of the word (e.g., *walked*, *cried*, *slithered*, etc.), though a largish subset of relatively frequent verbs (fewer than 200) are not (e.g., *fell*, *hit*, *chose*, *went*, etc.). Further, *-ed* is used productively with new or nonce words (e.g., *gutched*, *flonked*, *powed*, etc.), showing that something is going on beyond

* Tel.: +1-604-822-0984; fax: +1-604-822-9687.
E-mail address: stemberg@interchange.ubc.ca (J.P. Stemberger).

PII: S0364-0213(02)00088-5

simple rote memorization of forms and subsequent storage in the lexicon. It is often assumed that regular forms are not stored in the lexicon, but are created on-the-fly, either via a rule that combines a base form (e.g., *walk*) with *-ed*, or via constraints on output. It is sometimes assumed that irregular forms (e.g., *fell*), in contrast, are not produced by rule, but are stored as rote-memorized forms in the lexicon.

The extent to which rules are used is not clear, however. Within linguistics, many researchers (e.g., Kiparsky, 1982; Halle & Mohanan, 1985) have assumed that (symbol-based) rules are used for both regular and irregular forms. Recently, an approach known as Optimality Theory (e.g., Prince & Smolensky, 1993; Bernhardt & Stemberger, 1998; Smolensky, 1999), which abandons rules in favor of (symbol-based) constraints on output, has become one of the dominant theories in linguistics; regular and irregular patterns are both generated via constraints. Within the acquisition and speech production literatures, some researchers have taken the position that rules are never used for irregular forms but are always used for regular forms (e.g., Pinker & Prince, 1988, 1994; Kim, Pinker, Prince, & Prasada, 1991; Marcus et al., 1992, 1995; Pinker, 1991; Marslen-Wilson & Tyler, 1998; Clahsen, 1999). Many researchers take the position that rules are used much less often: most regular forms are stored in an unanalyzed fashion in the lexicon, and rules are used only for new forms (e.g., Butterworth, 1983; Pinker, 1984; Henderson, 1985; Caramazza, Laudanna, & Romani, 1988; Stemberger & MacWhinney, 1986). Others, especially those who take a connectionist approach, have argued that rules may never be used at all (e.g., Rumelhart & McClelland, 1986; MacWhinney & Leinbach, 1991; Plunkett & Marchman, 1991; Seidenberg & Daugherty, 1992; Stemberger, 1994a; Marchman, 1997; Plunkett & Juola, 1999). Bernhardt and Stemberger (1998) explore the possibility that symbol-based constraints are used for all forms, within a theory of acquisition. It is safe to say that the field has yet to reach consensus on this issue.

A main focus of this debate is how to account for differences in the behavior of regular and irregular forms. For example, irregular forms show strong effects of lexical frequency, but regular forms show much weaker frequency effects (Stemberger & MacWhinney, 1986; Sereno & Jongman, 1997) or no frequency effects (Pinker & Prince, 1988; Pinker, 1991; Marcus et al., 1992). Many of these differences are predicted if regular forms are always (or usually) produced via rules (or constraints) but irregular forms are stored in the lexicon (e.g., Stemberger & MacWhinney, 1986; Pinker, 1991). In contrast, irregular forms show strong effects of similarity to other irregular forms (Bybee & Slobin, 1982; Stemberger & MacWhinney, 1986; Pinker & Prince, 1988; Marcus et al., 1992; Marchman, 1997), while regular forms generally do not. Approaches that posit a single pathway for both regular and irregular forms need to account for these differences in some other way.

There is an orthogonal issue that has received far less attention: whether past-tense forms are generated in the same system as base forms. In linguistic approaches (e.g., Halle & Mohanan, 1985; Prince & Smolensky, 1993), inflected forms are in-principle subject to the same phonological constraints and biases as monomorphemic words. Further, for irregular forms, there is competition between the base form and the irregular form (or at least between the vowel of the base form and the vowel of the irregular form). Local connectionist models (e.g., Stemberger, 1985; Dell, 1986) also have competition between the base form and the irregular past-tense form, and situate inflectional morphology in the same network as basic phonological processing. In contrast, Rumelhart and McClelland (1986), along with all subsequent implemented distributed connectionist models of morphology and some symbolic models (e.g., Pinker, 1991), situate past-tense morphology in a specialized subnetwork that creates a specialized domain with phonological characteristics and statistics distinct from those of non-past-tense words, with no competition between base forms and past-tense forms. I will argue that models with specialized subnetworks for past-tense forms are in-principle incapable of accounting for the data presented in this paper.

Stemberger (1994a) has argued that many of the observed differences between regular and irregular forms might derive from natural confounds involving the two types of verbs. First, the two groups differ in terms of frequency. Some irregular forms are of much greater frequency than any regular forms, and irregulars have a greater mean frequency than regulars. Second, the two groups differ along phonological dimensions. When compared to the base forms of the same verbs, regular past-tense forms in English differ by having an extra phoneme or two at the end; e.g., *walked* is identical to *walk* except that it has a /t/ added at the end. Irregular forms, in contrast, most often have no added phonemes, but have a vowel that differs from the base vowel, e.g., /ow/ in *chose* versus /uː/ in *choose*. If we assume that base forms and past-tense forms are always stored in the lexicon and that they compete with each other during lexical access, the phonological differences between regular and irregular forms could conceivably lead to different behavior.[1] Stemberger (1990, 1991), examining speech errors of a purely phonological nature, has shown that the addition of a phonological element has very different statistical properties from the substitution of one phonological element for another. Bernhardt and Stemberger (1998, pp. 481–483), addressing phonological constraints on word-final consonants in children with (specific) language impairment, show how a seemingly independent phonological impairment on final consonants can lead to relatively good performance on irregular verbs like *sang* (with no consonant cluster) and very impaired performance on regular verbs like *walked* (with a final consonant cluster), even if regulars and irregulars are produced via the same mechanism.

While phonological and frequency confounds might in principle be able to account for differences, a detailed account has yet to be put forward. In this paper, I explore one type of morphological error (overtensing) in detail. I address whether the observed differences between regular and irregular forms could derive from inherent confounds with frequency and/or phonological factors. I argue that phonological factors are responsible for most of the observed effects, but that some small effect of regularity *per se* cannot be ruled out. Frequency confounds cannot account for the observed differences between regular and irregular forms, but the observed frequency effects do cause difficulties for many current models of past-tense production.

2. Overtensing errors

One phenomenon in which regular and irregular verbs behave differently is overtensing: an infinitive is replaced by a tensed form of the verb, when there is some higher verb (auxiliary or main verb) that appears in that tense. This was first reported for child language, with tensed verbs used erroneously with the auxiliary *did* (in positive questions or emphatic clauses) or *didn't* (in negative statements or questions) (Hurford, 1975; Kuczaj, 1976a; Fay, 1978; Maratsos &

Table 1
Adult overtensing errors (past tense)

	Did	Other verb
Regular	4	3
Irregular	18	14

Kuczaj, 1978). It was noted that most examples involve irregular verbs (1), but that some involve regular verbs (2).

1. (a) It didn't BROKE. (*correct*: It didn't BREAK.)
   (b) Did it FELL? (*correct*: Did it FALL?)

2. (a) I didn't PEED. (*correct*: I didn't PEE.)
   (b) They didn't SPILLED. (*correct*: They didn't SPILL.)

Stemberger (1982) reports that equivalent errors happen in adult speech, mostly with irregular forms. Some of these errors do not involve the auxiliary *did*, but rather some other higher verb (3).

3. (a) I forgot to WROTE—to *write*.
   (b) I heard somebody FLEW in here—*fly* in here.
   (c) "flavor" has failed to SUPPRESSED—to *suppress* "taste."

Stemberger's error corpus contains 39 errors involving past tense in a corpus of 7,500 adult errors of all types. Their distribution is given in Table 1. Note that errors are evenly split between auxiliary *did* and other main verbs. It should be noted, however, that without information about the frequency of these two types of syntactic construction in spontaneous speech, we cannot evaluate whether one or the other shows a higher error rate. Errors involving other main verbs have been overlooked in child language for a simple reason: overtensing was found through studies of auxiliary verbs, and errors with other verb complements were not looked for (Maratsos, 1992, personal communication). Such errors are attested in the ChiLDES database (MacWhinney, 2000):

4. (a) You missed me DID it. (*correct*: You missed me DO it.)
   (b) I heard it POPPED. (*correct*: I heard it POP.)

The utterance in (4a) is from Adam (Brown, 1973), and that in (4b) is from Abe (Kuczaj, 1976b). In diary studies of two children (see Stemberger, 1989, for details), I found the distribution of errors in Table 2.[2] The distribution of errors is similar to that of adults, except that *did* is overrepresented in the child errors, as compared to the adult errors.

Table 2
Child overtensing errors (past tense)

	Did	Other verb
Regular	3	0
Irregular	18	5

Irregular forms are overrepresented. Stemberger (1982) estimated that by chance about 58.3% of adult errors should involve irregular forms, significantly less than the 82.1% of Table 1. Pinker (1984) estimated chance for irregular forms at 53% for child speech, less than the 75.0% reported in Kuczaj (1976a) or the 86.4% in Table 2. Previous work has not provided a full explanation of why irregular forms are overrepresented but errors involving regular forms are nonetheless possible.

Many explanations for overtensing errors have focused on the syntactic nature of the error, thereby predicting incorrectly that all verbs, whether regular or irregular, should be equally subject to such errors. Early proposals argued for the misapplication of syntactic transformations (Hurford, 1975; Fay, 1978), but this has been shown to make many wrong predictions (Kuczaj, 1976a; Maratsos & Kuczaj, 1978; Pinker, 1984). Pinker (1984) suggested that overtensing might represent an error in which the speaker forgets that an infinitive should be used. Andrews (1990) discusses overtensing within Lexical Functional Grammar (LFG). He points out that, without special mechanisms, LFG always produces overtensed forms. In English, tense usually is mapped onto the main verb, and it is mapped onto auxiliaries. There is a special dependency, whereby tense is *not* mapped onto the main verb if it mapped onto an auxiliary, and a special mechanism is needed to express this dependency. Overtensing can result when the speaker fails to respect this dependency (whether systematically in the grammar, or for performance reasons on a given trial).

Other explanations focus on the preferential involvement of irregular forms. Pinker (1984) suggests that children have not realized that irregular past-tense forms are finite and so use them like infinitives. However, this is not a possible explanation for adult overtensing errors, which have the same basic characteristics as child overtensing errors. All researchers have suggested that irregular forms are overrepresented because they are stored in the lexicon while regular forms are created by rule, though the exact mechanisms are vague (Maratsos & Kuczaj, 1978; Pinker, 1984; Stemberger, 1982; Hollebrandse & Roeper, 1996); if forms are stored, they become available under the appropriate semantic conditions (past tense), and speakers use them erroneously in place of the infinitive. However, Pinker (1984) also noted that this provides no explanation for why regulars are involved at all.

There is currently no model that provides a full explanation for the known characteristics of overtensing errors. It is presumably for this reason that Pinker (1991) and Marcus et al. (1995) did not mention overtensing errors in an otherwise exhaustive discussion of differences between regular and irregular forms. Possible effects of lexical frequency and of phonological factors have never been explored. The possible role of confounds in the overinvolvement of irregular forms in overtensing errors has never been addressed.

One possible confound is lexical frequency. The most common intuition about overtensing is that irregular forms are erroneously accessed because they are stored in the lexicon. It is reasonable to assume that the irregular forms that are the easiest to access would be the forms most likely to be erroneously accessed. High-frequency irregular forms are more easily accessed than low-frequency irregular forms (e.g., Bybee & Slobin, 1982; Stemberger & MacWhinney, 1986; Marcus et al., 1992). It is *a priori* possible that high-frequency forms are more likely to be involved in overtensing; the greater the frequency of the tensed form, and hence the stronger its output form, the more likely overtensing might be. Irregular forms have a greater mean frequency than regular forms, including a greater number of ultra-high-frequency forms.

This frequency difference between regular and irregular verbs could in principle lead to the greater involvement of irregular verbs in overtensing, even if all past-tense forms are created via a single mechanism. This can be addressed by a careful study of the effects of lexical frequency.

A second possible confound is phonological form. Perhaps verbs where the past-tense form differs from the base form by having a different vowel (always irregular) are more often involved than verbs where the past-tense form is identical to the base form except for an additional consonant (almost always regular). This can be addressed by manipulating phonological factors.

Overtensing has so far been investigated using only spontaneous speech. Observational data have drawbacks, not least of which is the difficulty of controlling for confounds. In this paper, I use an experimental task designed to elicit overtensing errors from adults. In Experiment 1, I replicate the difference between regular and irregular forms observed in natural speech and investigate the role of lexical frequency. In Experiments 2 and 3, I investigate phonological factors.

3. Experiment 1: Past-tense forms

3.1. Method

3.1.1. The embedding task

The embedding task was developed to lead subjects to make involuntary overtensing errors in elicited speech. Subjects silently read a sentence and an additional verb presented on a computer screen, then, as rapidly as possible, combine them into a grammatical English sentence, using the additional verb as the auxiliary or main verb. Example stimuli are presented in Table 3.

All sentences have the following syntactic structure: (Determiner) Noun Verb (Preposition) (Determiner) Noun; length and complexity are balanced across the verb classes of interest. The sentence is presented centered just above the middle of the screen for 500 ms, after which another verb appears just below the sentence, in the targeted tense. The task is to take the second verb as soon as it appears on the screen and merge it with the sentence, using it as an auxiliary or main verb in a complex sentence, leaving no words out. Subjects are told to respond as quickly as possible. Instructions stress that the sentence should be grammatical, and example sentences are given where it is noted that the verb of the presented sentence usually changes

Table 3
Example stimuli for the embedding task

	Regular past	Irregular past
Subject sees	Harry dropped the pot.	Maria ate the pie.
Added after 500 ms	didn't	decided to
Subject says	Harry didn't DROP the pot.	Maria decided to EAT the pie.
OR	Harry didn't DROPPED the pot.	Maria decided to ATE the pie.

its morphological form in order to be correct. Including a variety of higher verbs increases the complexity of the task and may lead to a greater error rate than if just the auxiliary *didn't* is used for all trials.

On some trials, the embedded verb is erroneously produced in the past tense, so that it has the same form as in the original sentence. Note that there is an element of priming in the overtensing errors elicited in this way, because the past-tense form is always present in the original sentence. There may also be an element of priming in the overtensing errors observed in spontaneous speech. Utterances as in (5) occur in natural speech.

5. It broke. Why did it BROKE?

3.1.2. Materials

Fifty-six sentences were constructed, all containing a verb in the simple past-tense form, with the structure laid out above; all subgroups of verbs were balanced for the complexity of the sentence. Twenty-eight sentences contained regular verbs, and 28 contained irregular verbs. The irregular verbs were further divided into two subgroups of 14 verbs each, along a phonological dimension. One irregular subgroup contained past-tense forms that differ from the base forms only in that they have a different vowel (e.g., *found* vs. *find*, *ate* vs. *eat*). In the second irregular subgroup, there was a vowel difference combined with an added /t/ or /d/ at the end of the word (e.g., *felt* vs. *feel*, *sold* vs. *sell*). All groups and subgroups were equally divided along one additional dimension: high-frequency versus low-frequency. There were thus 14 high-frequency regulars, 14 low-frequency regulars, 7 high-frequency vowel-only irregulars, 7 low-frequency vowel-only irregulars, 7 high-frequency vowel + consonant irregulars, and 7 low-frequency vowel + consonant irregulars. It was planned to investigate the effects of frequency overall and within each main group (regular vs. irregular). The effect of phonological differences was planned only between the two subgroups of irregular verbs, not between regular verbs and subgroups of irregular verbs.

Between each subgroup of verbs, verbs were balanced for length (in letters and phonemes) and lexical frequency. Frequencies (from Francis & Kučera, 1982) are presented in Table 4.[3] Note that only *appropriate verb forms* were included in the frequency counts here; e.g., I did not include noun uses of *break* (e.g., "he took a break," "the breaking of the rules"), or adjectival or passive uses of *broken* (e.g., "the broken toy," "it got broken").

It was unclear what measure of frequency is best: the frequency of the past-tense form (which is presented: e.g., *broke*, *walked*), the frequency of the base form (which is the correct output: e.g., *break*, *walk*), the frequency of all forms in the paradigm combined (e.g., *break* + *breaks* +

Table 4
Mean frequencies for stimuli in Experiment 1

	Past tense		Base		Paradigm	
	High	Low	High	Low	High	Low
Regular	184.8	14.2	166.1	13.2	570.6	62.9
Vowel-only	382.1	14.9	577.4	19.3	1415.0	61.9
Vowel + consonant	391.9	13.6	217.0	20.0	842.9	72.7

broke + *broken* + *breaking*, *walk* + *walks* + $walked_{past}$ + $walked_{perfect}$ + *walking*), or some more complex measure. I attempted to control for all three of these measures. Low-frequency verbs were closely balanced for frequency across subgroups of verbs. Due to the small number of potential stimuli, it was not possible to balance the groups entirely for high-frequency forms. High-frequency regulars are of lower mean frequency than high-frequency irregulars, for all three frequency measures. The frequencies of the high-frequency past-tense forms are equated for the two subgroups of irregular verbs, but the frequencies of the base forms and the paradigms are higher for vowel-only verbs than for vowel + consonant verbs. I argue below that the frequency of the base form may be relevant, and will address whether these uncontrollable differences in frequency could have contributed to any observed differences in error rates.

For each subgroup of verbs, half of the stimuli involved the additional auxiliary verb *didn't*, and half involved some other higher verb. To ensure that this factor could not lead to differences between subgroups of verbs due to quirky interactions with particular verbs, two lists of stimuli were used. A given subject saw only List 1 or only List 2. Any sentence that involved *didn't* in List 1 involved some other higher verb in List 2, and vice versa. Thus, across subjects, half of all attempts at a given verb involved *didn't* and half involved some other higher verb. Each subject saw a given (lower) verb only once. For a given subject, half of the stimuli in each subgroup involved *didn't* and half involved some other higher verb. Each higher main verb was used the same proportion of times for each subgroup of verbs. One random order was generated for the sentences in List 1; all subjects who saw List 1 saw the stimuli in the same order. The stimuli in List 2 were in the same order as in List 1.

3.1.3. Procedure

Subjects were run individually. A subject sat in a sound-insulated booth in front of a high-quality microphone and a computer screen controlled by a Tandy 1200 computer. There were six practice trials, repeated if necessary (because some subjects had trouble with the fast pace of the experiment), in which the subject was given feedback on speed, loudness, and accuracy; all subjects were able to understand the task. Subjects were alternately assigned to List 1 or List 2, in the order in which they appeared for the experiment.

3.1.4. Subjects

Subjects were 60 undergraduate or graduate students at the University of Minnesota, who received for their participation in the experiment either money or extra credit in an introductory course in linguistics or psychology.

3.2. Results and discussion

Errors were identified by listening to the subject during the experiment and listening again to the tapes later on. Any response that was in doubt was analyzed acoustically to determine what was said, using a Voice Identification 2000 digital spectrograph. Overtensing errors were analyzed. Other errors, of relatively low frequency, involved failure to respond, repeating the presented sentence without modification, and inserting the added verb into the wrong part of the sentence. In some instances, the speaker stopped speaking partway through an irregular past-tense form (e.g., *so–sell*); these were few in number, and were included as overtensing errors.

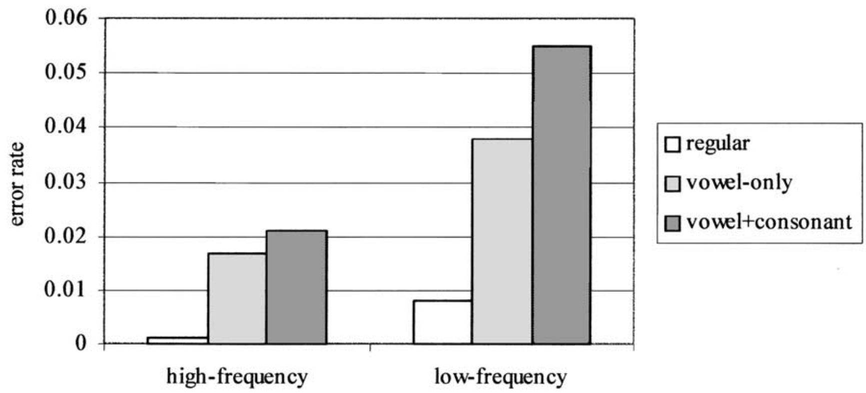

Fig. 1. Results of Experiment 1.

There was a main effect of regularity, as shown in Fig. 1. The results are expressed as proportion of trials in which there was an overtensing error; there were 840 trials for each cell for regular verbs, and 420 trials for each cell for irregular verbs. Results were analysed statistically using an analysis of variance.

Regular verbs were involved less often than irregular verbs (8 vs. 55 errors), with subject as random factor [$F_1(1, 59) = 28.51$, $p < .001$] and with word as random factor [$F_2(1, 52) = 16.75$, $p < .001$]. This replicates overtensing errors from natural speech. The two subgroups of irregular verbs did not differ from each other, with subject as random factor [$F_1(1, 59) = 1.49$, ns] or with word as random factor [$F_2(1, 24) < 1$], though there were slightly more errors with vowel + consonant verbs than with vowel-only verbs (32 vs. 23).

There was a main effect of frequency. Low-frequency verbs were involved significantly more than high-frequency verbs (46 vs. 17), with subject as random factor [$F_1(1, 59) = 16.22$, $p < .001$] and with word as random factor ($F_2(1, 52) = 6.38$, $p < .02$). This effect held separately for both irregular verbs [$F_1(1, 59) = 11.26$, $p < .001$; $F_2(1, 24) = 4.04$, $p = .056$] and regular verbs [$F_1(1, 59) = 3.77$, $p = .057$; $F_2(1, 26) = 5.20$, $p < .05$]. For the two subgroups of irregular verbs, effects of frequency were comparable (interaction Fs < 1). For regular versus irregular verbs, there was a significant interaction between regularity and frequency with subject as random factor [$F_1(1, 59) = 5.45$, $p < .025$] but not with word as random factor [$F_2(1, 52) = 2.19$, $p > .10$]; this results from a numerically smaller difference for regulars than for irregulars, but the number of observed errors is smaller than necessary to be sure of this interaction.

It did not matter whether the higher verb was *didn't* or some other main verb: regulars, 4–4; vowel-only, 11–12; vowel + consonant, 16–16. Equivalent effects in natural speech are unknown; the raw data in Table 1 above are uninformative, since chance is unknown.

In vowel + consonant irregular verbs, some overtensing errors (not included in Fig. 1) were only partial: a form of the verb was produced that was like the base form of the verb, except that the vowel or the consonant was like the past-tense form. These are presumably blends of the base and past-tense forms. The vowel of the base form combined with the final consonant of the past-tense form in *flee-d* ($n = 3$; cf. *flee* and *fled*), *hear-d* ($n = 1$; cf. *hear* and *heard*), *mean-t* ($n = 1$; cf. *mean* and *meant*), *deal-t* ($n = 1$; cf. *deal* and *dealt*) and *kneel-t* ($n = 1$; cf. *kneel* and *knelt*); note that the first two errors look like overregularizations (*flee-ed*, *hear-ed*), but that the remaining errors clearly are not. The vowel of the past tense combined with the lack of the final consonant of the base form, in *sole* ($n = 2$; cf. *sell* and *sold*).[4] Partial errors accounted for 22.0% of the errors on these verbs. There were more partial errors on low-frequency verbs than on high-frequency verbs (7 vs. 2). All partial errors occurred with *didn't*; it is unclear why that should be the case.

This experiment replicates the difference between regular and irregular past-tense forms observed in natural speech. In fact, the percentage of errors involving irregulars (87.3%) is not far from that of spontaneous adult speech in Table 1 above (82.1%). This difference does not derive from a confound with frequency, since it holds for low-frequency verbs that are closely equated for frequency. Although there is a strong effect of frequency, the differences observed in natural speech could not be due to a frequency confound. Because regular forms have a lower mean frequency than irregular forms, and low frequency forms are preferentially involved in overtensing, regular forms should be involved more than irregular forms in natural speech, the opposite of the observed effects. The apparent effect of regularity in natural speech is not due to a confound with frequency.

It is interesting that there were more errors on low-frequency past-tense forms than on high-frequency forms. One rationale for examining this factor was that the system might have a bias to output high-frequency forms. For simple past-tense forms like *broke* and *sang*, it has been shown that speakers are more likely to (correctly) output high-frequency forms (for adults: Stemberger & MacWhinney, 1986; for children: Bybee & Slobin, 1982; Marcus et al., 1995; Marchman, 1997). Since the irregular form is "forcing its way in" in overtensing errors, it made sense that strong high-frequency forms would force their way in more often than weak low-frequency forms. Experiment 1 shows that the opposite is true. I leave the ramifications of this finding for the final discussion.

Experiment 1 found no effect of phonological factors. The two phonologically defined subgroups of irregular verbs did not differ. However, for both irregular subgroups, the vowel of the past-tense form differs from the vowel of the base form. If this vowel difference is what drives error rates, then we would not expect them to differ. There was a nonsignificant difference between the two groups, with a slightly higher error rate on irregular forms that add a final consonant. It should be noted that, although the two groups were closely equated for the frequency of the past-tense forms, the mean frequency of the base forms was much lower for the vowel + consonant irregulars. If the frequency of the base form is relevant (as will be argued below), then a lower frequency base form will be associated with a higher error rate. Thus, the nonsignificant differences observed here, if real, could result from a confound with base-form frequency.

To control for phonological effects more fully, it is necessary to compare the subgroups of verbs in Experiment 1 with a different type of subgroup, where the past-tense form is irregular but can still be analyzed as a base form with a consonant added at the end. At least in American English, this cannot be investigated for past tense, since the only such irregular verb is *burnt* (cf. base *burn*); and even this has a regular variant (*burned*). There are a few additional forms in British English (e.g., *smellt*, *spillt*), but I do not have access to sufficient numbers of British English speakers. In order to investigate phonological issues, I am forced to use the perfect forms of verbs. There is a large subclass of irregular perfect forms in (all varieties of) English where the irregular suffix *-en* is added to the base form: *fallen*, *eaten*, *beaten*, *shown*, etc. If it is irregularity that gives a verb a high rate of overtensing errors, then verbs like *fallen* should have a high error rate, just like the irregulars *felt* and *found*. However, if it is having a different vowel from the base form that gives a verb a high error rate, then *fallen* should have a low error rate, just like the regulars *parked* and *tried*.

There is a second phonological confound that must also be addressed. In studies of natural speech involving adults or children, and in Experiment 1, the word following the target verb can begin with a consonant or with a vowel. This variable should not matter for irregular vowel-changing verbs. However, it has been shown to have an effect on regular past-tense forms. Guy (1991) has explored factors that can lead to the deletion of word-final consonants phonetically, and has shown that this is more likely when the next word begins with a consonant.[5] Deletion is a frequent occurrence in normal speech, even for past-tense forms. It is in-theory possible that regular forms are involved in overtensing just as much as irregular forms, but then the final /t/ or /d/ is deleted for phonological reasons, when the next word begins with a consonant. This can easily be controlled for. Guy has shown that consonant deletion is very infrequent when the next word starts with a vowel. In the embedding task, stimuli can be designed so that the next word always starts with a vowel. If regular forms are still involved less than irregular forms, it cannot be because of consonant deletion before a consonant.

4. Experiment 2: Perfect forms

4.1. Method

4.1.1. The embedding task

The same task was used as in Experiment 1. However, the sentences and additional verbs were in the perfect forms, as shown in Table 5. Since the negative form of *has eaten* is *hasn't eaten*, with the same form of the verb, it was possible only to use lexical main verbs like *decided* and *managed*, which Experiment 1 found to be comparable in effectiveness to the auxiliary *didn't*. Otherwise, the task is the same as in Experiment 1.

4.1.2. Materials

Fifty-four sentences were constructed, all with a verb in the perfect form, with the structure laid out in Experiment 1, and with the word after the verb beginning with a vowel. All subgroups of verbs were balanced for the complexity of the sentence. Eighteen sentences contained regular verbs, nine of high frequency and nine of low frequency. Eighteen sentences involved

Table 5
Example stimulus for Experiment 2

Subject sees	Maria has eaten a pie.
Added after 500 ms	has decided to
Subject says	Maria has decided to EAT a pie. <*correct*>
OR	Maria has decided to EATEN a pie. <*overtensing*>

Table 6
Mean frequencies for stimuli in Experiment 2

	Perfect form		Base		Paradigm	
	High	Low	High	Low	High	Low
Regular	81.2	7.2	96.2	4.9	343.0	24.3
-en	170.7	9.0	316.9	22.1	819.6	64.8
Vowel-changing	132.2	8.8	216.8	17.0	820.4	64.2

vowel-change-only or vowel-change + consonant irregular verbs, nine of high frequency and nine of low frequency; the two subclasses of verbs were mixed together, because they behaved the same in Experiment 1. Eighteen sentences contained irregular base + *-en* verbs, nine of high frequency and nine of low frequency. The three subgroups were balanced for length (in letters and phonemes) and lexical frequency. Frequencies (from Francis & Kučera, 1982) are presented in Table 6.

As in Experiment 1, it was impossible to control for frequency perfectly, especially for high-frequency verbs; given that low-frequency verbs are more prone to error, the uncontrollable differences would lead to greater error rates on regulars. Note that mean frequencies for high-frequency verbs are lower than in Experiment 1, reflecting differences in usage between perfect aspect and past tense. Each subject saw a given verb only once. Because there was only one type of added verb, only one list was used. Stimuli were placed in a single random order that was used for all subjects. Nine different main verbs were used, once for each subgroup of verbs.

4.1.3. Procedure

The procedure was the same as in Experiment 1, except that all subjects were exposed to the same list.

4.1.4. Subjects

Subjects were 60 undergraduate or graduate students from the same subject pool as in Experiment 1.

4.2. Results and discussion

The data were analyzed in the same fashion as in Experiment 1. Results are shown in Fig. 2. Results were analysed statistically using an analysis of variance. The proportion of errors in each cell is based on 540 trials per cell.

Vowel-changing irregular verbs were involved significantly more often than regular verbs [$F_1(1, 59) = 74.62$, $p < .001$; $F_2(1, 32) = 9.33$, $p < .005$] and than irregular *-en* verbs [$F_1(1, 59) = 45.53$, $p < .001$; $F_2(1, 32) = 6.42$, $p < .02$]. The error rate on *-en* irregulars was slightly higher than that of regulars, significant with subject as random factor [$F_1(1, 59) = 6.02$, $p < .02$], but not with word as random factor [$F_2(1, 32) = 3.13$, $p < .09$].

There was an overall effect of frequency with subject as random factor [$F_1(1, 59) = 12.74$, $p < .001$], but not with word as random factor [$F_2(1, 48) = 2.42$, $p > .10$]. There was also an

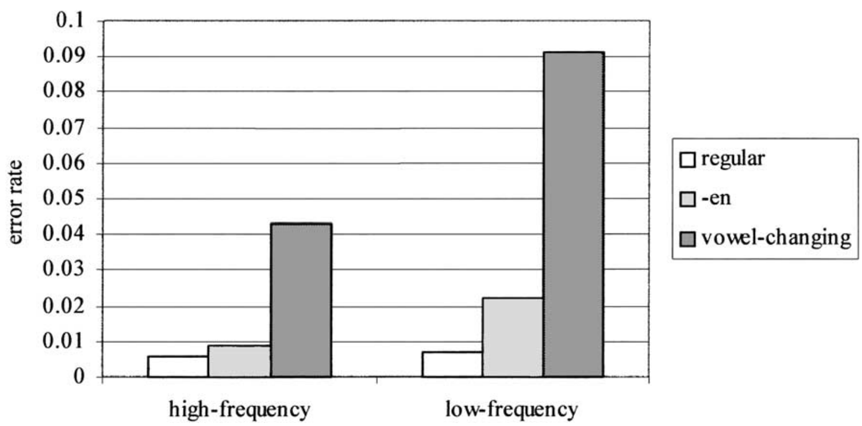

Fig. 2. Results of Experiment 2.

interaction of frequency with verb subgroup, with subject as random factor [$F_1(2, 118) = 9.00$, $p < .001$], but not with word as random factor [$F_2(2, 48) = 1.07$, $p > .30$]. The interaction arose because the few errors on regular verbs were almost evenly distributed over high and low frequency verbs, and the low error rate with *-en* verbs made it difficult to tease apart morphological versus lexical effects.

As in Experiment 1, there were more errors on low-frequency verbs than on high-frequency verbs. However, the effect did not reach significance for regular verbs. Due to differences in the statistics of past-tense and perfect aspect in English, there was a much smaller frequency difference between high and low frequency verbs in Experiment 2, especially for regular verbs; this may have contributed to the smaller effects. These findings are suggestive, but the frequency effect found in Experiment 1 for regular verbs needs to be replicated.

Experiment 2 replicates the finding that regular forms are involved in overtensing less than vowel-changing irregular forms. This is true despite the fact that one phonological confound was removed: the next word always began with a vowel; this makes it unlikely that the *-ed* suffix was present but was then deleted or was difficult to detect for phonological reasons. The greater involvement of vowel-changing irregular forms thus reflects factors internal to the verb, and is not due to interactions between the verb and the phonological environment in the following word.

The greater part of the difference in error rates is due to the difference between vowel-changing verbs versus suffixing verbs (whether regular *-ed* or irregular *-en*). The small increase in overtensing errors with *-en* as compared to *-ed* might suggest that there is some small effect of regularity (at least for low-frequency verbs). However, even if this small increase is reliable, it could derive from an uncontrollable phonological difference that is inherent in these two suffixes: *-en* has a nasal consonant, but *-ed* has a stop consonant. The two phonemes /n/ and /d/ have very different statistical properties in English. Suppose that there is a bias in overtensing errors for the errors to create incorrectly tensed verbs with high-frequency phonological properties; this is reasonable in, e.g., Dell's (1986) model of speech production. Would such a bias lead to a greater involvement of *-en* or of *-ed*?

Consider perfect forms that end in an unstressed syllable, such as *eaten* versus *heated*. The *-en* forms end in a syllabic [n̩], and the *-ed* forms end in [əd]. An analysis of the bisyllabic words in the Francis and Kučera (1982) word frequency count shows that words ending in [n̩] are more frequent than words ending in [əd] in both type frequency (1,178 vs. 579) and token frequency (13,387 vs. 4,161). This difference is exaggerated in words where the [n̩] and the [əd] are not separate morphemes (type: 824 vs. 65; token: 10,375 vs. 919). In that portion of the English vocabulary outside of inflected forms, there is a huge statistical skewing towards [n̩]. In overtensing errors, in which an uninflected word is the target, could there be a bias towards [n̩] in the output? Fig. 3 provides a *post-hoc* break-down of the data in Experiment 2, contrasting the errors for *-ed* and *-en* for the two environments attested for *base* + *-en* verbs: after a vowel versus with a final unstressed syllable. Error rates are low and comparable for *-ed* and *-en* after a vowel, and are also low for regular perfect forms ending in [əd]. Perfect forms with [n̩], in contrast, have a much higher error rate, even with high-frequency verbs. Although this analysis does not prove that the differential involvement of *-en* is purely phonological, it certainly suggests such an interpretation.

When looking at uncontrolled error data, overtensing errors appear to show a difference between regular and irregular forms, a difference that can plausibly arise if irregular forms are stored in the lexicon but regular forms are created via rules. On further investigation, it turns out that regularity may not be relevant; the apparent effect of regularity may derive from natural confounds with phonological form. Once phonological form is controlled for, it is clear that regularity *per se* is not the main contributor to the observed difference; phonological factors are far more important. It remains unclear whether regularity has any effect at all, because the

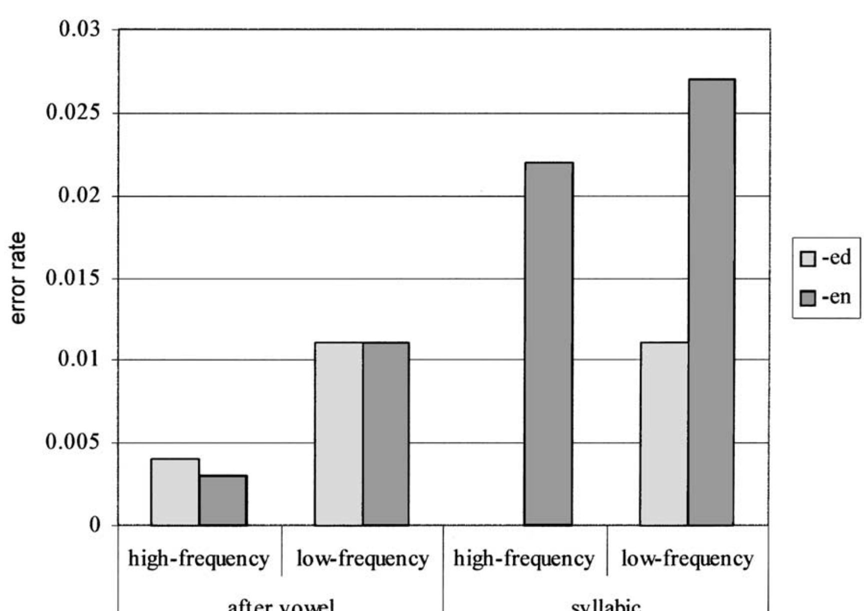

Fig. 3. *Post-hoc* analysis of Experiment 2, *-ed* vs. *-en* by environment.

pronunciation differences between regular and irregular forms do not allow us to fully control for all phonological variables.

This has implications that go far beyond overtensing errors. There are many instances where regular and irregular forms behave differently, and phonological form is confounded with regularity in almost every study (e.g., Pinker, 1991; Marslen-Wilson & Tyler, 1998; Clahsen, 1999; Gordon, 1985). Experiment 2 provides evidence that phonological factors can underlie differences between regular and irregular forms. Merely showing that regulars and irregulars behave differently must be viewed as uninteresting, until it can be demonstrated that phonological confounds do not underlie the differences.

Pinker and Prince (1994) suggested that no single difference between regular and irregular forms proves that regular forms are created by rule while irregular forms are stored. However, they maintained that all the data are explained by making this one assumption, while non-rule-based accounts must bring in different explanations for each phenomenon, so that no single reason underlies all the differences. This argument is interesting only insofar as all the observed differences are explained by the rule versus storage distinction for regulars and irregulars. This distinction makes the wrong predictions about overtensing, which must be explained in some other way. Given that some differences require a separate explanation, this makes Pinker and Prince's argument less compelling.

Unfortunately, we have run into phonological confounds between regular and irregular forms that are inherent in their pronunciation differences. Is it possible to unconfound these phonological factors completely? What is needed is a situation in which the phonological sequences found in regular forms have higher phonological frequencies than those associated with irregular forms, so that the phonological biases would predict greater error rates involving regular forms. English does not uncontroversially provide any such inflectional pattern.

There is potentially one, albeit highly speculative, way in which regularity might be unconfounded from phonological differences in English. Ullman and Pinker (1990) and Ullman (1993) argued that regulars are stored in the lexicon (like irregulars) in one circumstance that is useful here: when both regular and irregular forms of the verb are grammatical, such as *shined* and *shone*, or *dived* and *dove*. They noted that most irregular forms cannot vary, even irregulars of comparable (low) frequency. In order to account for which verbs can vary and which cannot vary, it may be necessary to store the "regular" variant in the lexicon as a possible output. This argument has potential implications for overtensing errors: if irregulars are more often involved in overtensing because they are stored in the lexicon, then any regulars that are stored in the lexicon should *also* show a greater rate of overtensing errors. In contrast, the phonological hypothesis predicts that variable regular forms like *dived* should be involved at the same low rate as nonvariable regular forms. Experiment 3 investigates this possibility.

5. Experiment 3: Variable verbs

5.1. Method

5.1.1. Task

The same task was used as in Experiment 1.

5.1.2. Materials

Eighteen verbs were identified that could appear as either regular or irregular in the same sentence with the same basic meaning, where the irregular form was vowel-changing (with or without a suffix): *crept*/*creeped*, *dove*/*dived*, *dreamt*/*dreamed*, *hung*/*hanged*, *knelt*/*kneeled*, *leapt*/*leaped*, *lit*/*lighted*, *pled*/*pleaded*, *shone/shined*, *slew*/*slayed*, *slunk*/*slinked*, *snuck*/*sneaked*, *sped*/*speeded*, *strove*/*strived*, *swept*/*sweeped*, *wept*/*weeped*, *wove*/*weaved*. In order to have as many variable verbs as possible, one verb was included that is variable only in the perfect form (in standard English): *swollen*/*swelled*. All these verbs are of low frequency. In addition, the suffixing irregular *burnt*/*burned* was included. Nine nonvariable vowel-changing verbs and nine nonvariable regular verbs were added, balanced for frequency and length. It was necessary to have half the number of nonvariable verbs of each class so that each subject dealt with the same number of verbs in each category: nine variable regular, nine variable irregular, nine nonvariable regular, and nine nonvariable irregular.

Thirty-seven sentences were constructed, most containing a verb in the past tense, with the structure laid out in Experiment 1, with the word after the verb always beginning with a vowel. One sentence was in the perfect form. All subgroups of verbs were balanced for the complexity of the sentence. Two lists were constructed. Both lists had the same sentences involving the nonvariable vowel-changing and regular verbs, and with *burnt*. The 18 variable verbs were arbitrarily divided into two groups: 9 were presented in List 1 in their irregular form, 9 were presented in their regular form; in List 2, the regularity of the variable verbs was reversed, with no other changes in the sentence. The stimuli in List 1 were placed in one random order, used for all subjects; the stimuli in List 2 were in the same order. Subjects were alternately assigned to List 1 or List 2, in the order in which they appeared for the experiment.

Only main lexical verbs were used as added verbs. Nine different main verbs were used, once in each subgroup of verbs.

5.1.3. Procedure

The procedure was the same as in Experiment 1.

5.1.4. Subjects

Subjects were 60 undergraduate or graduate students from the same subject pool as in Experiment 1.

5.2. Results and discussion

The data were analyzed in the same fashion as in Experiment 1. Results are shown in Fig. 4. The proportion of errors shown for each cell is based on 540 trials per cell. Results were analyzed statistically using an analysis of variance.

For nonvariable verbs, irregular verbs were involved more often than regular verbs [$F_1(1, 59) = 12.21$, $p < .001$; $F_2(1, 16) = 9.26$, $p < .01$], replicating Experiments 1 and 2. For variable verbs, irregular forms were involved more than regular forms [$F_1(1, 60) = 50.83$, $p < .001$; $F_2(1, 17) = 6.99$, $p < .02$]. The variable irregulars were involved more often than the nonvariable irregulars by subject analysis [$F_1(1, 60) = 18.45$, $p < .001$]; item analysis was not possible, given the differences inherent in the task (9 nonvariable irregulars seen by

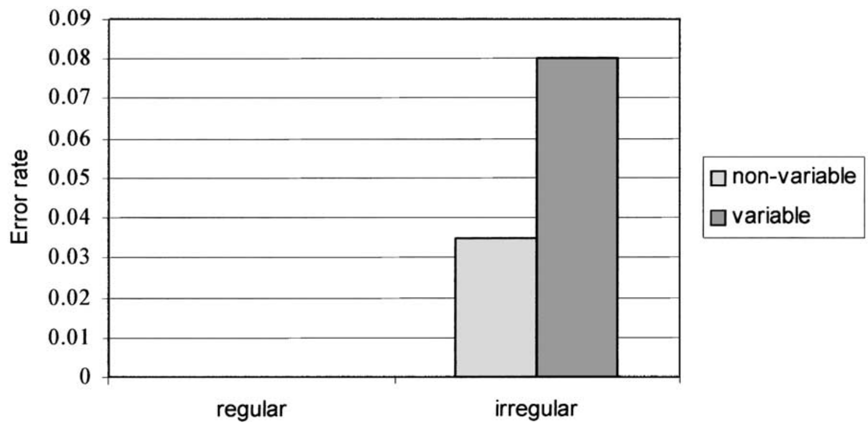

Fig. 4. Results of Experiment 3.

60 subjects each, but 18 variable irregulars seen by 30 subjects each). No errors were made on regulars, whether variable or nonvariable; the two types of regulars do not differ. No errors were observed with *burnt*, but since even an unrealistically high error rate of 7% would have led to only four observed errors, this is not informative.

Variable regular verbs were not more prone to overtensing errors than nonvariable regular verbs. If regular variants are stored in the lexicon like irregulars, this result entails that lexical storage is not what is responsible for making irregulars prone to overtensing. This result is expected if phonological factors underlie this phenomenon, since variable regulars and nonvariable regulars are phonologically equivalent. However, the claim by Ullman and Pinker (1990) and Ullman (1993) that variable regulars are stored in the lexicon may be wrong, in which case this experiment leaves us with little additional information.

Irregular forms that vary with regular variants show the highest error rates of all. This suggests that there are lexical properties that affect error rates. I address below whether this effect makes sense in models of speech production.

6. Underlying mechanisms

I have concluded that overtensing errors do not show that the observed differences between regular and irregular forms derive from regularity *per se*; it is not simply the case that lexically-stored irregular forms are erroneously forcing their way into the sentence. It is now time to address mechanisms in more detail. The results are most natural within models that posit a single mechanism for regular and irregular past-tense forms, but are in-principle compatible with a dual-mechanism model (though probably not with any current dual-mechanism model). The results are not compatible with models that use a specialized subnetwork for past-tense formation (whether for all verbs, or just for irregular forms).

Experiment 1 found a frequency effect within regular verbs. Connectionist models of all types predict such effects on regulars, though at a lower magnitude than with irregular verbs

(Stemberger & MacWhinney, 1986; Seidenberg & Daugherty, 1992). Most dual-mechanism models are unable to account for frequency effects on regular verbs (e.g., Prasada, Pinker, & Snyder, 1990; Pinker, 1991; Marcus et al., 1992; Clahsen, 1999). However, there was no frequency effect on regulars in Experiment 2. Before we can reject the dual-mechanism model on the basis of frequency effects on regulars, we must be more certain that the effect is there. I will not address this issue further here, but I believe that the data do suggest that frequency effects are present with regulars.

A key observation for understanding overtensing errors is that it is semantically appropriate to mark past tense on the verb, but that a syntactic mechanism normally prevents this from occurring (Stemberger, 1982; Andrews, 1990). In some models, this automatically leads to competition between base forms and past-tense forms. It also relates overtensing to a more general issue within language production: how a speaker successfully isolates each semantic element in a message and packages it accurately in different words. Bock (1982) observed that, in general, a given semantic element is mapped onto only one word in the sentence.[6] On occasion, however, speakers erroneously package some piece of information twice. MacKay (1980) observed that adults make errors like those in (6), which he calls displaced synonymic intrusions.

6. (a) Is this the lid for this TOP? 'jar'
   (b) We ALWAYS never do that. 'almost'

In (6a), the word *top* is erroneously accessed because it is a contextual synonym for *lid*—but it replaces the semantically unrelated word *jar*; as a result, the meaning {lid} is mapped onto the sentence twice, using distinct lexical items. In (6b), the word *always* is accessed in place of target *almost* because it is semantically related to the following word *never* (an antonymic intrusion). Stemberger (1983) shows that the intruding word usually bears a phonological resemblance to the word that it replaces; the phonological similarity of *always* and *almost* is obvious, and even *jar* and *top* have the same vowel (in the dialect of the speaker). In overtensing, the semantic feature {PAST-TENSE} is present in the context, and so is available for leakage in this fashion; the feature {PAST-TENSE} is erroneously mapped onto two words in the sentence. Overtensing can be viewed as a special instance of such double expression of semantic information, including the expected phonological effects.

I begin with a description within the type of model that most successfully accounts for the results presented here: single-mechanism competition models. This is followed by a discussion of how dual-mechanism models fail (but could in-principle be made to work), and why non-competition models fail.

6.1. Single-mechanism competition models

Overtensing errors can be derived in a straight-forward fashion in models in which the base and past-tense forms compete with each other, at a level where phonological factors can have an effect. In order to capture the observed standard frequency effect, with fewer errors involving high-frequency verbs, very specific characteristics must be present in the model. Models of this sort are successful, whether they are symbolic or connectionist in nature. At this point, it is difficult to differentiate the symbolic versus connectionist models empirically; I routinely use models of both types in my own work.

Stemberger (1982, 1985) presents a local connectionist analysis in which <BREAK> and <BROKE> are competing word units. Stemberger (1994a) points out that these forms are in a hyperonym relationship: <BREAK> is a high-frequency general term, the meaning of which is a proper subset of the meaning of <BROKE>. Levelt (1989) points out that special mechanisms are needed in order for a speaker to access the lower-frequency hyponym, when the additional meaning elements are present. Thus, <BREAK> is normally accessed under a broad set of conditions, but <BROKE> is accessed only if the semantic element {PAST-TENSE} is present. In the target phrase *didn't break*, {PAST-TENSE} should be expressed only on the auxiliary, but semantic leakage provides an intermediate level of activation to <BROKE>, such that it will occasionally be accessed erroneously, leading to an overtensing error.

In local connectionist models, adjacent levels interact, and there are consequently phonological effects in lexical access (e.g., Stemberger, 1982; Dell, 1986). A past-tense form will sum activation from {PAST-TENSE} with activation resulting from competition at the phonological level. If the competition between the vowels in *break–broke* and *sleep–slept* results in more activation to the past-tense form than the competition between a consonant versus no consonant in *fall–fallen* and *need–needed*, then overtensing errors involving *broke* and *slept* will be more common than errors involving *fallen* and *needed*. If phonological factors (such as the type or token frequency of the final syllable) favor *fallen* over *needed*, there will be a difference between suffixing irregulars and regulars, as observed in Experiment 2. In principle, a system of this sort can derive all of the effects observed in this study, though a simulation capturing the details of the phonological processing effects would be desirable.

The most successful model is one in which past-tense forms are processed within the same network that processes all words (as standardly assumed in the local connectionist and linguistics literatures), because the past-tense forms are sensitive to the phonological characteristics of the language as a whole. Syllabic [n̩] is more frequent than [əd] in English as a whole, but not in the perfect-form subset of the vocabulary. Among the bisyllabic perfect forms in Francis and Kučera (1982), [n̩] is lower than [əd] in both type frequency (9 vs. 205) and token frequency (748 vs. 1,545). In order for the difference between *-en* and *-ed* in overtensing errors to be derived from phonological frequencies, those frequencies must be computed over all words in the lexicon, and cannot be computed just over perfect forms. Bernhardt and Stemberger (1998) and Stemberger and Bernhardt (2001) argue that this is necessary to derive all the effects that are observed with the development of inflected forms in the speech of very young children. They argue that it is frequency of phonological sequences in the language as a whole that predicts which verbs successfully mark past tense and plurals first, not frequency within the past-tense domain. For example, in English as a whole, word-final /st/ (as in *first*, *best*, *kissed*, etc.) is far more frequent than word-final /zd/ (as in *buzzed*, *used*, etc.), but the reverse is true within the domain of past-tense forms. Nonetheless, a child may master past-tense forms ending in /st/ before mastering past-tense forms ending in /zd/. Only a network that sums frequencies across all inflected and uninflected forms makes the right predictions.

A distributed connectionist model of sentence production, along the lines of Dell, Juliano, and Govindjee (1993), may also be able to derive overtensing. This is a recurrent network, in which the input (a semantic representation of a proposition) remains constant during the production of a sentence. Because the semantic input is the same for all words in the sentence, semantic leakage (where a given piece of semantic information is produced twice) arises naturally. The system iterates through the sentence one phoneme at a time. When processing the phrase *didn't break*, there is competition between the different surface realizations of the word "*break*." There is no competition for the /b/ and the /r/, but then competition arises between /ey/ and /ow/, especially since the semantic unit {PAST-TENSE} is active in the proposition. Any phonological factor that is relevant to either segment would contribute to the resolution of the competition. With suffixing forms, the competition is between having reached the end of the word (*fall* and *need*) versus continuing with additional segments (*fallen* and *needed*). If suffixing constitutes a phonologically less intense competition, such errors will be less common. If continuing with syllabic [n̩] has a higher transitional probability than continuing with [əd] (due to differences in phonological frequency), then errors with syllabic [n̩] will be more common. In principle, such a model can account for the differences between regular versus suffixing irregular versus vowel-changing irregular verbs reported here; but the simulations have not yet been extended to morphology.

There exists a symbolic model that is quite similar: Optimality Theory, currently one of the dominant approaches in the field of linguistics, which Smolensky (1999) describes as a symbolic adaptation of connectionist models. Optimality Theory is based on competition between alternative output forms. For past-tense forms, whether regular or irregular, there is competition between the base form and the past-tense form. The system must choose one form over the other in the output. Phonological factors regularly have effects on morphology in human language (McCarthy & Prince, 1993), and mechanisms have been developed to both account for them and predict them. Bernhardt and Stemberger (1998) explored phonological effects on simple past-tense and plural forms in early child speech. The presence of phonological effects on overtensing is not difficult to derive. The apparent difference between regular and irregular forms can be derived via phonological effects in this approach.

Accounting for the effect of frequency on overtensing errors is possible, but only if very specific assumptions are made about processing. We observed a standard frequency effect, with fewer errors involving high-frequency verbs. Some models instead predict *anti*-frequency effects, with more errors involving high-frequency verbs than involving low-frequency verbs.

Consider first how a local connectionist model with a linear activation function would behave. In local models, resting activation levels for a word unit are related to lexical frequency: high-frequency words have high resting levels, and require less input activation in order to be accessed. MacKay (1976) reported that the frequency of base forms is strongly correlated with the frequency of past-tense forms; people generally use the same verbs with high or low frequency regardless of the tense or syntactic construction that is used. For high-frequency forms such as <BREAK> and <BROKE>, activation levels are greater for both base and past-tense forms than for low-frequency forms such as <STINK> and <STUNK>; as a result, a speaker will make fewer lexical and phonological errors on verbs like *break* than on verbs like *stink*. However, the high frequency of <BROKE> would not necessarily lead to greater *morphological* accuracy than on low-frequency forms such as <STUNK>, since its competitor <BREAK> is also usually of high frequency. Based on empirical findings (e.g., Marcus et al., 1992; Stemberger & MacWhinney, 1986), however, we can be sure that the high frequency of <BROKE> gives it a greater competitive advantage over its competing base form relative to the low-frequency form <STUNK>: children and adults make fewer errors on high-frequency irregular past-tense forms (*break*, *breaked*) than on low-frequency irregular past-tense forms (*stink*, *stinked*). When the sentence is appropriate for an irregular past-tense form, high frequency allows the past-tense form to more reliably out-compete the base form (even though the base form is also of high frequency).

In overtensing errors, however, the past-tense form is not correct; the semantic unit {PAST-TENSE} gives some activation to the past-tense forms, but not as much as with simple past-tense forms. This leads to lower activation levels for <BROKE> and <STUNK> than in the processing of simple past-tense forms, and makes them weaker competitors. The speaker usually produces a base form, but occasionally produces an overtensing error.

The nature of the activation function determines whether overtensing errors are predicted to show a frequency effect or an anti-frequency effect. A linear activation function leads to an anti-frequency effect. A nonlinear activation function can lead to a standard frequency effect. Suppose the following hypothetical mean resting activation values for simple past tense:

high-frequency base: .20	low-frequency base: .15
high-frequency past: .17	low-frequency past: .10

activation from semantic units: .60
activation from {PAST-TENSE}: .10

In simple past tense, we derive the following mean values:

high-frequency base: .80	low-frequency base: .75
high-frequency past: .87	low-frequency past: .80

In a particular trial, activations fall into a distribution around the mean. On some trials, the base form's activation falls near the maximum of its distribution, and the past-tense form falls near the minimum of its distribution; an error results. Because the means are further apart for high-frequency forms than for low-frequency forms, there are fewer errors in the processing of high-frequency forms.

In phrases such as *didn't break* and *didn't stink*, activation from {PAST-TENSE} is decreased from .10 to, say, .02. This leads to the following mean activation levels:

high-frequency base: .80	low-frequency base: .75
high-frequency past: .79	low-frequency past: .72

There is now a greater spread of mean activation levels for low-frequency forms, and hence a lower rate of overtensing errors is predicted. There should be an *anti*-frequency effect, with more errors involving high-frequency past-tense forms. A linear (fully additive) activation function cannot account for the bias to output high-frequency forms in simple past tense, without erroneously creating the same output bias in overtensing errors.

However, a nonlinear activation function can correctly derive a frequency effect in overtensing errors. At different points on a nonlinear activation function, the same input activation can have different effects on the activation of the output. For low-frequency forms, if {PAST-TENSE} inputs .10 units of activation, this may lead to an increase of .10 in the output. At the high activation levels of high-frequency forms, this could be magnified to .20, leading to very accurate access of high-frequency forms. If {PAST-TENSE} inputs only .02 units in overtensing errors, the resulting effects might be .015 for low-frequency forms, and .025 for high-frequency forms. But the high-frequency base is further up the activation curve than the low-frequency base. The result is a larger activation difference for high-frequency forms than for low-frequency forms, and fewer errors: overtensing should preferentially involve low-frequency verbs. The results of this study thus support the notion that activation functions are nonlinear.

Variable irregulars show the highest error rates of all. The variability of these verbs can be modelled by assuming a lower resting activation level for such verbs. This makes the verbs behave like ultra-low-frequency verbs, with "error" rates that are so high on simple past-tense forms that speakers accept the regularized variants like *dived* as correct variants of the past-tense form. Positioning these verbs lower on the activation curve will also exaggerate the rate of overtensing errors, so that there is a greater error rate than with non-variable low-frequency irregular forms.

Single-mechanism models that posit competition between base and past-tense forms, interacting with phonological processing, can in principle account for all of the effects reported in this study. It does not appear to matter whether the model is a local connectionist, distributed connectionist, or symbolic model.

6.2. Dual-mechanism competition models

Unlike single-mechanism models, dual-mechanism models cannot derive the high error rate of vowel-changing irregulars versus the low error rate of suffixing forms (whether regular or irregular) in a simple fashion. There must be two sources of error that conspire to produce this result. One source must affect regulars and irregulars impartially. The other source must target irregulars only, but be sensitive to phonological factors, which requires competition between the base forms and the irregular past-tense forms. It is just a coincidence that *-ed* and *-en* are both suffixes *and* show lower error rates.

In the models of Marslen-Wilson and Tyler (1998) and Clahsen (1999), the processing of regular inflected forms is modular, and the phonology of the base cannot affect whether the regular rule applies or not. The low rate of overtensing errors involving regulars can only be viewed as an effect of regularity *per se*. However, overtensing errors cannot arise solely because irregular forms are stored rather than rule-generated, because regular forms are also involved in these errors. The only obvious source of error that can affect regular forms is syntactic: the erroneous generation of a syntactic structure calling for a past-tense form rather than for an uninflected verb. This syntactic error will affect all verbs equally, regardless of regularity or phonological factors. To this is added a second source of error involving the erroneous access of an irregular past-tense form for a syntactic structure which calls for an uninflected verb. It is unclear why such an error should occur; perhaps the presence of the feature [+past-tense] elsewhere in the sentence confuses the mechanism that accesses and inserts lexical items into syntactic structures, leading it to erroneously select a past-tense form. However, this error must be sensitive to phonological factors; it must be rare with *-en* after vowels as in *thrown*, more common with *-en* as [n̩] as in *taken*, and most common with vowel-changing verbs. Whether irregulars are statistically more likely to be involved than regulars depends entirely on the statistical likelihood of the two types of errors. Consider Experiment 1, in which regular and vowel-changing verbs each account for 50% of all trials. If the syntactic error is just as frequent as the lexically-based error, then vowel-changing verbs should be involved about 75% of the time (since they would be involved in all of the lexically-based errors, and half of the syntactic errors); this is close to the observed proportions. If the lexically-based error rate involving irregulars in *-en* is very low, then most of the errors involving *-en* irregulars would arise from the syntactic error, and the error rate would be very close to (but slightly greater than) the error rate involving regulars (as in Experiment 2).

To implement these phonological factors requires competition between the base form and the irregular past-tense form. Marslen-Wilson and Tyler (1998) treat base and irregular forms as competing words, so competition is present. Unfortunately, their model is too vague to know whether phonological factors can affect this competition, and whether such phonological competition is sensitive only to statistical probabilities within the past-tense system or (as I have argued is necessary) to the phonological statistics of English as a whole. Tyler, Randall, and Marslen-Wilson (2002) express skepticism about the role of phonology in morphological errors, so it is probable that their system cannot account for the effects reported here. Clahsen (1999) suggests that irregular forms are stored within the main lexical entry for a word, but as changes from the base form rather than as a full form (one of the suggestions of Stemberger, 1985, for local connectionist models). The word *broke* would be stored as /breyk/ and /ow/. During production, the two parts of the irregular lexical entry are combined to create the phonological form /browk/. In principle, the process of combining the two parts may be subject to general properties of phonological processing. If phonological biases favor a particular combination, the error rate may be elevated relative to other irregular forms. However, Clahsen's model is too vague to know whether the combination process would be sensitive to phonological factors.

Frequency effects are more challenging for these models. Manipulating the nature of the activation function in order to derive a standard frequency effect does not seem to be an option at least in Clahsen's approach. For Clahsen, and probably also for Marslen-Wilson and Tyler, the competition between the base and past-tense forms should show a bias towards high-frequency irregular forms, in both simple past tense (with fewer errors involving high-frequency forms) and in overtensing environments (with more errors involving high-frequency forms). However, neither model is presented in enough detail that we can be certain of this.

Although these dual-mechanism models posit the competition that is needed to derive the effects reported in this paper, it is not clear that any current model of this sort can account for the standard frequency effects found in overtensing errors or the role of phonological factors. However, it seems likely that a model could be developed that would account for the effects. One limitation, however, is that all such models must view the low error rate involving *-en* irregulars as entirely unrelated to the low error rate involving regular *-ed* forms; it is just a coincidence that both types of verb involve suffixes. Whether a dual-mechanism approach is viewed as viable depends on which coincidences a researcher is willing to accept.

6.3. Two-step models without competition

There are models that do not posit competition between base forms and past-tense forms during processing. Rumelhart and McClelland (1986) presented a distributed connectionist model of learning in which base forms were mapped onto past-tense forms in a specialized subnetwork that produces just past-tense forms. Almost all more recent models for the learning of morphologically inflected forms have shared this characteristic (e.g., MacWhinney & Leinbach, 1991; Plunkett & Marchman, 1991); Plunkett and Juola (1999) is a slight exception, in that they map base forms onto both past-tense forms and plurals. Pinker (1991) and Pinker and Prince (1994) adopt a dual-mechanism variant of these models, using the specialized subnetwork only for irregular past-tense forms. In none of these models is there competition between a base form and a past-tense form. A learner learns how an element in the input base form maps onto the output past-tense form. This sort of model has difficulty with both the phonological effects and the frequency effects reported here.

The place of these models in the overall task of producing speech has been vague. Presumably, the phonological form of the base form is accessed in a general word-accessing network. For past-tense forms, the result is then used as the input to the specialized subnetwork for past-tense forms (for all verbs, or for just irregulars, depending on the theory) or to the specialized subnetwork for all inflected forms (Plunkett & Juola, 1999). One must ask why this complexity exists. A more straight-forward connectionist model would not have this extra step. These two-step models appear to be connectionist implementations of rule-based symbolic models (which inherently have two steps in the creation of regular inflected forms by rule). The fact that two-step models in principle cannot account for the characteristics of overtensing errors reported here is not a problem for distributed connectionist models in general, but simply points the way to a different class of model, such as that of Dell et al. (1993), discussed above.

One major drawback to a two-step model is that the specialized subnetwork for inflected forms inherits none of the frequency characteristics of the main lexical network. It cannot be expected to show sensitivity to, e.g., the higher frequency of [n̩] in English as compared to [əd]; instead, it will show sensitivity to the fact that, in perfect forms, [əd] is of greater frequency than [n̩]. It seems unlikely that a two-step single-mechanism model can account for the results of Experiment 2. Two-step dual-mechanism models are unable to account for the results of Experiment 2 due to a second major drawback of two-step models.

The second major drawback derives from the way that the specialized subnetwork generates inflected forms from base forms. The subnetwork is trained on simple past-tense forms, and maps the base form onto the past-tense form. The subnetwork accomplishes that task with different rates of success for different classes of verbs. For single-mechanism models, the subnetwork has the highest success rate with regular verbs. For irregular verbs, the subnetwork is most successful with high-frequency irregular forms. Clearly, the subnetwork learns the input-to-output mappings of regulars better than the mappings for irregular forms, and for high-frequency forms better than for low-frequency forms.

Overtensing must result when a verb is erroneously shunted into the specialized subnetwork for past tense. Differences between verbs are determined only by the subnetwork, so all verbs must be equally likely to be shunted into the subnetwork. The subnetwork outputs the verbs as past tense with the same level of accuracy that it always does. In single-mechanism models, overtensing errors will be most likely to involve regular verbs (for which the input–output mappings have been learned best), somewhat less likely to involve high-frequency irregular forms, and least likely to involve low-frequency irregular forms. In dual-mechanism models, high-frequency irregular forms should be involved more often than low-frequency irregular forms. These predictions are the exact opposite of the results of Experiments 1 and 2.

For perfects, the relative error rate for *-en* perfects and for vowel-changing perfects should correlate with the relative error rates for other types of morphological error. The greater rate of overtensing errors involving vowel-changing verbs versus *-en* suffixing verbs is expected only if *-en* perfects are in general less prone to error; e.g., if errors like *falled* for 'fallen' and *see-ed* for 'seen' are rare compared to errors like *sinked* for 'sunk' and *selled* for 'sold.' To my knowledge, there has been only one study that allows us to evaluate this prediction. Stemberger (1994b) examined both types of perfect forms in an experimental sentence production task, and found that both had error rates of about 4% in neutral unprimed sentences. This suggests that the rates of overregularization errors are comparable for vowel-changing and *-en* suffixing perfect forms. Two-step models are unable to account for the lower rate of overtensing errors involving *-en* irregulars.

These two-step models fail to account for the characteristics of overtensing errors for fundamental reasons: the specialized subnetwork has learned the mapping from input to output in a way that will result in the same probability of success whether the output is the target (a simple past-tense form) or an overtensing error. Such models predict frequency effects for simple past tense but anti-frequency effects for overtensing. From the perspective of the model, the two effects are the same thing: a bias to output high-frequency forms. For competition-based models above, we were able to avoid this by allowing the high frequency of the base form to enable the base form to out-compete the past-tense form. This is not a possible option in two-step models. High-frequency base forms usually have high-frequency past-tense forms, giving the system more learning trials and leading to a better-learned mapping; without competition, the frequency of the base form cannot affect processing of the past-tense form in any other way. A characteristic of two-step models that is a strength for simple past-tense forms becomes a weakness for overtensing: by taking advantage of the characteristics of the isolated subdomain, the subnetwork loses the ability to deal with the characteristics of the main network. There is no way to modify two-step models to derive a standard frequency effect on errors in both simple past-tense and overtensing environments.

Models with specialized subnetworks are quite simply unable to derive the characteristics of overtensing errors. They must be abandoned. There is in principle no problem for developing a distributed connectionist model for morphology (along the lines of Dell et al., 1993, though none has yet been developed). Such a system has the advantage that the learner would not need to do anything special to learn past-tense forms (unlike the Rumelhart & McClelland, 1986, model, which requires the child to figure out that a specialized subnetwork for past-tense forms is needed).

6.4. Extension beyond English past and perfect forms

I have discussed the issues so far in terms of the past-tense and perfect forms of verbs in English. However, the issues are more general in scope.

The most obvious extension is to work on plurals in compounds. In English compounds, the first member can have plural reference, but is generally required to be uninflected; e.g., a pot-maker usually makes many pots, not just one pot, but speakers do not say *pots-maker*. This is similar to the use of the uninflected verb in the phrase *didn't break* (though not identical, because the plurality of the first noun in the compound is not overtly expressed elsewhere in the sentence). Gordon (1985) reported that children readily produce novel compounds with irregulars as the first member (e.g., *mice-eater*), but rarely with regular plurals as the first member (e.g., *rats-eater*). This task has been frequently used (a recent example being van der Lely & Ullman, 2001). Researchers using this task have universally assumed that differences between regular and irregular forms reflect storage for irregulars versus rule-generation for regulars. However, phonological confounds similar to those with past tense (suffixing regulars vs. vowel-changing irregulars, for English) are always present, with no attempt to show that there is an effect of regularity separate from the phonological confounds. Given the results of this study on overtensing, it is reasonable to suggest that the apparent effect of regularity in compounds may derive from phonological confounds. Future work on compounds needs to address this possibility.

Data from other languages would also be quite relevant, especially if the language can fully unconfound phonology and regularity. With English, we ran into the problem that phonological output frequencies were greater with the irregular suffix *-en* than with the regular suffix *-ed*, leaving open the possibility that *-en* is more prone to overtensing errors because there is a bias towards high-frequency phonological sequences in the output. What is needed is an instance where the regular affix is of the same type as the irregular affix (prefix, suffix, infix, or vowel change), and is associated with higher phonological sequence frequencies. If there is still a greater involvement of irregulars (even though irregulars involve the creation of lower-frequency phonological sequences), that would appear to be evidence for the effect of regularity *per se*. Perhaps a situation of this sort can be identified and studied in some other language, bringing a more straight-forward resolution to this debate.

7. Conclusions

I have examined overtensing errors in adult speech, using the embedding task. I have replicated findings from natural speech which show that irregular forms are more likely to be involved in overtensing. It was found that frequency confounds did not contribute to the apparent effect of regularity; the tendency for low-frequency forms to be involved in overtensing would lead to a greater involvement of regular verbs in natural speech, which is not the case. Nor does it matter whether the next word begins with a consonant or with a vowel, removing a confound with Final Consonant Deletion, in which the *-ed* of regular verbs could be deleted for phonological reasons when the next word begins with a consonant. However, regularity *per se* cannot account for all of the data. In Experiment 2, it was shown that irregular *base* + *-en* perfects have an error rate almost as low as regulars; verbs in which the past and perfect forms have a vowel that is different from the vowel of the base form of the verb are preferentially involved in overtensing. Even the small difference between *-en* and *-ed* might be due to phonological factors. A *post-hoc* analysis of the data from Experiment 2 showed that verbs with [n̩] (as in *fallen*) are involved more in overtensing than verbs in which the *-en* is realized as nonsyllabic [n] after a vowel (as in *thrown*); the error rate for nonsyllabic *-en* is comparable to that of *-ed*. The differential involvement of [n̩] can be attributed to a phonological output bias favoring final syllabic [n̩] in English, which is of much greater frequency than final [əd].

However, the effects of regularity *per se* cannot be ruled out, as long as one is willing to accept it as a coincidence that *-ed* and nonsyllabic *-en* both have low error rates and both are suffixes. Experiment 3 showed that variable regular forms are no more likely to be involved in overtensing than nonvariable regulars, despite some claims that variable regulars are listed in the lexicon and thus are in a sense irregular (Ullman & Pinker, 1990; Ullman, 1993). If Ullman and Pinker's proposal is correct, then regularity *per se* clearly has no influence on overtensing errors. In any event, there is no evidence that regularity plays any role in overtensing. Although the data do not rule out dual-mechanism accounts, current dual-mechanism models such as Marslen-Wilson and Tyler (1998) and Clahsen (1999) are very vague, and there is reason to believe that neither model in its current form can account for the results presented here.

One of the most important findings of Experiments 1 and 2 was that there is a standard frequency effect in overtensing: errors are more likely with low-frequency verbs. Models that posit specialized subnetworks for past-tense forms (whether single-mechanism connectionist models or dual-mechanism symbolic models) fail completely, because they predict anti-frequency effects in overtensing errors. Only models that derive the base form and the past-tense form in the same network can account for the results here, and even then require nonlinear activation functions. Although no simulated distributed connectionist model of inflectional morphology has had the right characteristics, models that have addressed other domains of language (such as that of Dell et al., 1993) are likely to succeed, as are local connectionist models (e.g., Stemberger, 1985; Dell, 1986). Certain symbolic models (such as the variant of Optimality Theory developed by Bernhardt and Stemberger, 1998) are also promising.

Regularity *per se* does not necessarily underlie all observed differences between regulars and irregulars. Without question, the largest effect in overtensing errors in adult speech is the distinction between vowel-changing versus suffixing inflected forms; any effect of regularity *per se* is smaller at the very least. In any argument that regularity *per se* underlies an observed difference between regulars and irregulars, it clearly does not suffice to merely observe that a difference is present, as done ubiquitously in the literature (e.g., Pinker, 1991; Marcus et al., 1995; Marslen-Wilson & Tyler, 1998; Clahsen, 1999). More complex arguments are needed to prove that the differences derive from regularity *per se*. Even if regularity *per se* is important, that does not prove that rules are needed, given the recent development of linguistic theories such as Optimality Theory that have eliminated rules and replaced them with constraints. More research is needed before we will know whether regularity, much less rules, is an independent property of morphological processing in human languages.

The results here rule out the most prominent models on both sides of the connectionist-symbolic debates of the 1980s and 1990s. It is time to move on to other more adequate (and more interesting) models of human language.

Notes

1. This is also true if rules are used for all forms. Modifying a phonological form by adding a phoneme is not comparable to modifying the phonological form by changing something. Speakers may find one type of operation easier to learn or perform, for purely phonological reasons.

2. These numbers are meant to establish the existence of these errors. Both children produced overtensing only rarely, so that the errors may have been nonsystematic errors, comparable to the errors in adult speech. Collection methods for these errors were also comparable to studies of adult speech. I am currently involved in a study of overtensing in young children using the ChiLDES database where exact rates of such errors can be computed.
3. Francis and Kučera (1982) was used for frequency information because the corpus was tagged in a way that eliminates ambiguities relevant to morphology. For example, the corpus allows us to eliminate noun uses of *break* and *breaking*, and passive or adjectival uses of *broken*, to focus in on the frequency of usage of the forms of the verb *to break*. Some alternative frequency counts that are sometimes used in psychological studies, such as Zeno (1995), are based on untagged corpora and do not disambiguate words enough to be used in studies of morphological processing.
4. Stemberger (1982) reports one instance of *sole* in overtensing in natural speech.
5. Browman and Goldstein (1986) have argued that the final /t/ or /d/ is not deleted, but is acoustically hidden due to overlap of gestures with the following consonant. This is an equivalent explanation, for our purposes here. With both explanations, the /t/ or /d/ has no acoustic realization, and a listener would not be able to hear it. If overtensing occurred with a regular verb, it could easily be missed.
6. Grammars may systematically violate this principle as a means of encoding other information. For example, if a noun and adjective both are marked for the same gender, it may help the listener realize that the adjective modifies that particular noun.

Acknowledgments

This study was supported in part by NSF Research Grant #DBS-9209642 to the author.

References

Andrews, A. D. (1990). Unification and morphological blocking. *Natural Language* & *Linguistic Theory, 8*(4), 507–557.

Bernhardt, B. H., & Stemberger, J. P. (1998). *Handbook of phonological development: From the perspective of constraint-based nonlinear phonology*. San Diego, CA: Academic Press.

Bock, J. K. (1982). Towards a cognitive psychology of syntax: Information processing contributions to sentence formulation. *Psychological Review, 89*(1), 1–47.

Browman, C. P., & Goldstein, L. M. (1986). Towards an articulatory phonology. *Phonology Yearbook, 3,* 219–252.

Brown, R. (1973). *A first language: The early stages*. Cambridge, MA: Harvard University Press.

Butterworth, B. (1983). Lexical representation. In B. Butterworth (Ed.), *Language production: Vol. 2, Development, writing, and other language processes* (pp. 257–294). London: Academic Press.

Bybee, J. L., & Slobin, D. I. (1982). Rules and schemas in the development and use of the English past tense. *Language, 58*(2), 265–289.

Caramazza, A., Laudanna, A., & Romani, C. (1988). Lexical access and inflectional morphology. *Cognition, 28*(3), 297–332.

Clahsen, H. (1999). Lexical entries and rules of language: A multidisciplinary study of German inflection. *Brain & Behavior Science*, *22*(6), 991–1060.

Dell, G. S. (1986). A spreading activation theory of retrieval in sentence production. *Psychological Review*, *93*(3), 283–321.

Dell, G. S., Juliano, C., & Govindjee, A. (1993). Structure and content in language production: A theory of frame constraints in phonological speech errors. *Cognitive Science*, *17*(2), 149–195.

Fay, D. (1978). Transformations as mental operations: A reply to Kuczaj. *Journal of Child Language*, *5*(1), 143–149.

Francis, W. N., & Kučera, H. (1982). *Frequency analysis of English usage: Lexicon and grammar*. Boston: Houghton Mifflin.

Gordon, P. (1985). Level ordering in lexical development. *Cognition*, *21*(1), 73–93.

Guy, G. R. (1991). Explanation in variable phonology: An exponential model of morphological constraints. *Language Variation and Change*, *3*(1), 1–22.

Halle, M., & Mohanan, K. P. (1985). Segmental phonology of Modern English. *Linguistic Inquiry*, *16*(1), 57–116.

Henderson, L. (1985). Towards a psychology of morphemes. In A. W. Ellis (Ed.), *Progress in the psychology of language* (Vol. 1, pp. 15–72). London: Lawrence Erlbaum.

Hollebrandse, B., & Roeper, T. (1996). The Concept of DO-Insertion and the theory of INFL. In C. Koster & F. Wijnen (Eds.), *Proceedings of the Groningen Assembly on Language Acquisition* (pp. 261–271). Groningen, The Netherlands: Groningen Center for Language & Cognition.

Hurford, J. R. (1975). A child and the English question formation rule. *Journal of Child Language*, *2*(2), 299–301.

Kim, J. J., Pinker, S., Prince, A., & Prasada, S. (1991). Why no mere mortal has ever flown out to center field? *Cognitive Science*, *15*(2), 173–218.

Kiparsky, P. (1982). From cyclic phonology to lexical phonology. In H. van der Hulst & N. Smith (Eds.), *The structure of phonological representations, part 1* (pp. 130–175). Dordrecht, Holland: Foris.

Kuczaj, S. A. (1976a). Arguments against Hurford's 'Aux Copying Rule'. *Journal of Child Language*, *3*(3), 423–427.

Kuczaj, S. A. (1976b). *-ing,-s and-ed: A study of the acquisition of certain verb inflections*. Unpublished doctoral dissertation, University of Minnesota.

Levelt, W. J. M. (1989). *Speaking: From intention to articulation*. Cambridge, MA: MIT Press.

MacKay, D. G. (1976). On the retrieval and lexical structure of verbs. *Journal of Verbal Learning and Verbal Behavior*, *15*(2), 169–182.

MacKay, D. G. (1980). Speech errors: Retrospect and prospect. In V. A. Fromkin (Ed.), *Errors in linguistic performance: Slips of the tongue, ear, pen, and hand* (pp. 319–332). New York: Academic Press.

MacWhinney, B. (2000). *The CHILDES project: Tools for analyzing talk* (3rd ed.). Mahwah, NJ: Lawrence Erlbaum Associates.

MacWhinney, B., & Leinbach, J. (1991). Implementations are not conceptualizations: Revising the verb learning model. *Cognition*, *40*(1/2), 121–157.

Maratsos, M., & Kuczaj, S. A. (1978). Against the transformational account: A simpler analysis of auxiliary overmarkings. *Journal of Child Language*, *5*(1), 337–345.

Marchman, V. (1997). Children's productivity in the English past tense: The role of frequency, phonology, and neighborhood structure. *Cognitive Science*, *21*(3), 283–304.

Marcus, G. F., Brinkmann, U., Clahsen, H., Wiese, R., Woest, A., & Pinker, S. (1995). German inflection: The exception that proves the rule. *Cognitive Psychology*, *29*(3), 189–256.

Marcus, G. F., Pinker, S., Ullman, M., Hollander, M., Rosen, T. J., & Xu, F. (1992). Overregularization in language acquisition. *Monographs of the Society for Research in Child Development*, *57*(4), 1–182.

Marslen-Wilson, W. D., & Tyler, L. K. (1998). Rules representations and the English past tense. *Trends in Cognitive Sciences*, *2*(11), 428–435.

McCarthy, J. J., & Prince, A. S. (1993). *Prosodic morphology I: Constraint interaction and satisfaction*. Rutgers University Cognitive Sciences Center Technical Report-3, Piscataway, NJ.

Pinker, S. (1984). *Language learnability and language development*. Cambridge, MA: Harvard University Press.

Pinker, S. (1991). Rules of language. *Science*, *253*(5), 530–535.

Pinker, S., & Prince, A. S. (1988). On language and connectionism: Analysis of a Parallel Distributed Processing model of language acquisition. *Cognition*, *28*(1), 73–194.

Pinker, S., & Prince, A. S. (1994). Regular and irregular morphology and the psychological status of rules of grammar. In S. Lima, R. L. Corrigan, & G. K. Iverson (Eds.), *The reality of linguistic rules* (pp. 321–350). Amsterdam: John Benjamins.

Plunkett, K., & Marchman, V. (1991). U-shaped learning and frequency effects in a multi-layered perceptron: Implications for child language acquisition. *Cognition*, *38*(1), 43–102.

Plunkett, K., & Juola, P. (1999). A connectionist model of English past tense and plural morphology. *Cognitive Science*, *23*(4), 463–490.

Prasada, S., Pinker, S., & Snyder, W. (1990, November). *Some evidence that irregular forms are retrieved from memory but regular forms are rule-generated*. Paper presented at the Annual Meeting of the Psychonomics Society, New Orleans.

Prince, A. S., & Smolensky, P. (1993). *Optimality Theory: Constraint interaction in generative grammar*. Rutgers University Cognitive Sciences Center Technical Report-2, Piscataway, NJ.

Rumelhart, D., & McClelland, J. (1986). On learning the past tenses of English verbs. In D. Rumelhart & J. McClelland (Eds.), *Parallel distributed processing: Explorations in the microstructure of cognition* (Vol. 1, pp. 216–271). Cambridge, MA: Bransford Books.

Seidenberg, M. S., & Daugherty, K. (1992, November). *Rules or connections? The past tense revisited*. Paper presented at the 33rd Annual Meeting of the Psychonomic Society, St. Louis, MO.

Sereno, J. A., & Jongman, A. (1997). Processing of English inflectional morphology. *Memory and Cognition*, *25*(4), 425–437.

Smolensky, P. (1999). Grammar-based connectionist approaches to language. *Cognitive Science*, *23*, 589–613.

Stemberger, J. P. (1982). *The lexicon in a model of language production*. Doctoral dissertation, UCSD. New York: Garland Publishing Inc., 1985.

Stemberger, J. P. (1983). Inflectional malapropisms: Form-based errors in English morphology. *Linguistics*, *21*(4), 573–602.

Stemberger, J. P. (1985). An interactive activation model of language production. In A. W. Ellis (Ed.), *Progress in the psychology of language* (Vol. 1, pp. 143–186). London: Lawrence Erlbaum.

Stemberger, J. P. (1989). Speech errors in early child language production. *Journal of Memory and Language*, *28*(2), 164–188.

Stemberger, J. P. (1990). Wordshape errors in language production. *Cognition*, *35*(2), 123–157.

Stemberger, J. P. (1991). Apparent anti-frequency effects in language production: The addition bias and phonological underspecification. *Journal of Memory and Language*, *30*(2), 161–185.

Stemberger, J. P. (1994a). Rule-less morphology at the phonology–lexicon interface. In R. Corrigan, G. Iverson, & S. Lima (Eds.), *The reality of linguistic rules* (pp. 147–169). Amsterdam: John Benjamins.

Stemberger, J. P. (1994b, November). *Phonological priming and irregular past: For whom the bell telled*. Paper presented at the 35th Annual Meeting of the Psychonomic Society, St. Louis, MO.

Stemberger, J. P., & Bernhardt, B. H. (2001, April). *U-shaped learning in language development, and restrictions on error correction*. Paper presented at the Biennial Meeting of the Society for Research in Child Development, Minneapolis. Rutgers Optimality Archive ROA-472.

Stemberger, J. P., & MacWhinney, B. (1986). Frequency and the lexical storage of regularly inflected forms. *Memory and Cognition*, *14*(1), 17–26.

Tyler, L. K., Randall, B., & Marslen-Wilson, W. D. (2002). Phonology and neuropsychology of the English past tense. *Neuropsychologia*, *40*(8), 1154–1166.

Ullman M. T. (1993). *The computation of inflectional morphology*. Unpublished doctoral dissertation, Massachusetts Institute of Technology.

Ullman M. T., & Pinker S. (1990). *Why do some verbs not have a single past tense?* Paper presented at the 15th Annual Boston University Conference on Language Development, Boston, MA.

van der Lely, H. K. J., & Ullman, M. T. (2001). Past tense morphology in specifically language impaired and normally developing children. *Language and Cognitive Processes*, *16*(2/3), 177–217.

Zeno, S. (1995). *The educator's word frequency guide*. Brewster, NJ: Touchstone Applied Science Associates.