Children's Productivity in the English Past Tense: The Role of Frequency, Phonology, and Neighborhood Structure

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The productive use of English past tense morphology in school-aged children (N = 74; 3 years, 8 months to 13 years, 5 months) is explored using an elicited production task. Errors represented 20% of the responses overall. Virtually all of the children demonstrated productivity with regular (e.g., good) and irregular patterns (zero-marking, e.g., sit → sit; vowel-change, e.g., ride → rid). Overall frequency of errors decreased with age, yet the tendency for certain types of irregularizations increased in the older groups. Analyses across items indicated that all error types were predicted by combinations of item frequency, phonological characteristics of stems and past tense forms, and aspects of phonological past tense "neighborhoods." Contrary to "hybrid" or dual-mechanism models incorporating a phonologically-insensitive default mechanism (e.g., Prasada & Pinker, 1993), these results suggest that children's productivity with regular and irregular patterns is consistent with a phonologically-based constraint satisfaction system similar to that implemented in connectionist models (Daugherty & Seidenberg, 1992; Plunkett & Marchman, 1991, 1993).

INTRODUCTION

An important recent debate in cognitive science concerns the basis for productive language use. That is, what mechanisms underlie children's and adult's ability to generate appropriately inflected nonsense verbs like ricked (Berko, 1958) or to produce incorrect additions of a past tense suffix to an irregular verb such as putted (e.g., Bybee & Slobin, 1982; Cazden, 1968; MacWhinney, 1978; Marcus et al., 1992). Within most symbolic models, productivity requires a system of grammatical symbols and "rules" which operates independently of features of individual lexical items (Marcus et al., 1992; Pinker, 1991; Prasada & Pinker, 1993). An alternative view proposes that productivity is best framed in terms...
of a constraint satisfaction mechanism in which rule-like generalization emerges over the course of learning. For example, recent connectionist models have shown that interactions among factors such as item frequency and phonological attributes of stems and past tense forms can account for several acquisition and processing phenomena (Daugherty & Seidenberg, 1992; MacWhinney & Leinbach, 1991; Plunkett & Marchman, 1991, 1993; Rumelhart & McClelland, 1987). In this article, we evaluate children's elicited past tense errors with respect to a key distinction between these two models, in particular, the conditions under which English speakers are sensitive to lexical-level phonological information when demonstrating productivity in their native language.

Symbolic rule-based accounts of the acquisition of the English past tense traditionally suppose that children's first verbs are learned as clusters of individual lexical items that are not decomposed into their grammatical components (e.g., stem and suffix) and that do not explicitly represent the regular past tense rule. Early in development, generalization to novel forms is rare, and verbs tend to appear as unmarked stems, for example, daddy go, or in their correct regular, for example, walk → walked, or irregular form, for example, throw → threw. The onset of suffixation errors marks the acquisition of the rule, independent of lexical learning, which now applies as a default grammatical operation unless an irregular alternative is successfully retrieved (i.e., "block-and-retrieval-failure," Marcus et al. 1992; Pinker, 1991; Prasada & Pinker, 1993). Lexical learning mechanisms are still operative, but are downsized to tracking associative links between the relatively few clusters of irregulars and to generating the occasional "irregularized" form, such as glow → glew (by analogy to grow → grew) (Kim, Pinker, Prince, & Prasada, 1991; Prasada & Pinker, 1993; Xu & Pinker, 1995). In sum, a dual-mechanism view posits that:

irregular pairs are stored in a memory system that superimposes phonological forms, fostering generalization by analogy, and regulars are generated by a default suffix concatenation process capable of operating on any verb, regardless of its sound (Prasada & Pinker, 1993, p. 2).

Rejecting a strong distinction between rule-based and associative mechanisms, an alternative account relies on a single constraint satisfaction mechanism which is sensitive to item-level features. For example, Plunkett and Marchman (1993) utilized distributed phonological representations of verbs that were analogous to English and trained networks to learn regular and irregular mappings between stems and past tense forms. The training set reflected several key factors about the frequency, phonological structure, and number and distribution of regular and irregular English verbs. These networks successfully resolved the competition between regular and irregular mappings by encoding item-level cues to the appropriate output in the set of weights that interconnected the inputs and outputs, via an intermediate layer of representations. The models did not incorporate an explicit distinction between regular and irregular forms, yet learned all mappings when the training set was small and later generalized both irregular and regular patterns to known and novel forms. In the networks, both early correct output and subsequent erroneously regularized and irregularized forms are generated via a single mechanism which resolves competitions among probabilistic patterns of item-level features, in this case, frequency, phonological
PAST TENSE PRODUCTIVITY

To summarize, a key difference between these dual- and single-mechanism models of inflectional morphology centers on the role for phonology in speakers' productive use of past tense forms. Evidence for a dual-mechanism model comes from reports that spontaneous irregularizations, but not regularizations, tend to be phonologically similar to existing irregular forms (Bybee & Moder, 1983; Marcus et al., 1992; Xu & Pinker, 1995). In addition, speakers appear to tune into phonological similarity when judging the "goodness" of irregularized nonsense verbs, but not regularized ones (Prasada & Pinker, 1993). On the other hand, Stemberger's (1993) reanalysis of the corpora from Marcus et al. (1992) showed that children's regularization errors do reflect a sensitivity to phonological features of stems and past tenses. Recently, Marchman and Callan (1995) reported that adults were more likely to add a suffix to irregular verb stems which were phonologically similar to several (rather than one or two) regular verbs in an on-line task. These latter findings are consistent with the single-mechanism prediction that phonological information is relevant to speakers' production of regularized, as well as irregularized, past tense forms.

In the context of these conflicting findings, our goal here is to evaluate the extent to which phonological information is predictive of children's correct and erroneous production of the past tense forms of common monosyllabic English verbs. Elicited production tasks allow for analyses of error patterns across a fixed set of items, offering a controlled means of tapping into factors underlying productive language use. Picture-book versions are appropriate for children who span a broader age range than those typically reported in naturalistic corpora. Furthermore, these tasks avoid the metalinguistic demands required when making judgments of nonsense forms. After briefly reviewing key developmental trends in error production, we evaluate the role of item frequency, phonological features of stems and past tense forms, and patterns of phonological similarity in determining the tendency for children to erroneously use the regular suffix with irregular verbs. We then examine the degree to which one type of irregularization, zero-marking, is predicted by the same set of factors. We should note that there is some controversy over whether zero-marking errors should be considered to be examples of productive language use. For example, Xu and Pinker (1995) excluded these types of errors from their analyses of "weird past tense forms" in the CHILDES database citing the difficulty of distinguishing spontaneously produced unmarked past tense errors from other types of unmarked verb forms. This limitation does not arise when interpreting zero-marked forms in an elicitation task (e.g., Bybee & Slobin, 1982; Marchman, 1988; Marchman, Wulfeck, & Ellis Weismer, 1996) if it can be demonstrated that children understand that the context requires a simple past tense form and that their error patterns are systematic.

To preview the predictions under consideration here, we outline key item-level characteristics of two common English irregular verbs, throw and hit. First, both of these verbs are likely to be quite familiar to speakers in their past tense forms, threw and hit (as indexed by item frequency), and are hence more likely to be accurately produced compared to a lower-frequency irregular past tense form (e.g., spit). However, throw and hit vary with respect to other item-level characteristics that contrast in how they are proposed to impact attributes of stems and/or past tense forms, and "neighborhoods" of phonologically-based clusters of items.
children's errors in single- versus dual-mechanism models of the production of inflectional morphology.

Borrowing from Glushko (1979) and others (e.g., Jared, McRae, & Seidenberg, 1990), both throw and hit belong to fairly substantive "neighborhoods" of stems which are similar in key aspects of their overall phonological shape. For our purposes, neighborhood is defined with respect to phonological attributes that are proposed to be relevant to the clustering of past tense forms, that is, stem-final vowel or vowel-consonant sequence, or "rhyme" (Pinker & Prince, 1988). Initial consonant/consonant cluster is free to vary across neighbors. In this scheme drink, sink, and blink would be members of the same neighborhood, but sip, sit, and sap would not. Thus, this definition of neighborhood captures only a subset of the possible phonological relationships that could obtain across lexical items (cf. Bybee & Moder, 1983).

Figure 1 compares several key aspects of the structure of the past tense neighborhood for the pairs throw → threw and hit → hit. Note first that both throw → threw and hit → hit have several "friends" which share a similar mapping pattern from stem to past tense form (e.g., blow → blew, grow → grew, fit → fit, pit → pit). A friendly neighborhood organization is typical of English irregular verbs, and it makes sense that the correct production of an irregular past tense form should be facilitated by the phonological conditioning that derives from membership in a cluster of similarly-sounding items. In addition, this clustering should also increase the probability of a speaker producing, say, glew as the past tense

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*Verbs that have two alternative past tense forms are counted as 0.5 in each category.*

**Figure 1.** Past tense neighborhood structure for two common English monosyllabic verbs.
of *glow* or *sit* as the past tense of *sit*. Bybee and Slobin (1982) report that verbs with a stem-final alveolar consonant, such as */t/* or */d/*, which defines membership in the zero-marking class of English verbs, were more likely to be zero-marked than nonalveolar stems by preschool- and elementary-aged children.

At the same time, as shown in Figure 1, *throw* and *hit* differ substantially in number of “enemies,” that is, similarly-sounding verbs which have dissimilar past tense forms. In a single-mechanism model, similarity is a source of confusion across all verb types and should increase speakers’ tendency to produce both regularized and irregularized forms. On this basis, we would predict that *throw* will be considerably more likely to be suffixed than *hit*. However, in a dual-mechanism model, suffixation occurs by default, operating independently of the fact that *throw* has 13 neighbors which are suffixed (e.g., *show*, *sew*, *flow*, etc.), compared to *hit* which has only few suffixed enemies (Kim, Pinker, Prince, & Prasada, 1991; Marcus et al., 1992; Prasada & Pinker, 1993).

We can note finally that the correct production of irregular past tense forms has been shown to be influenced by specific phonological attributes of stems and past tense forms, only indirectly captured by our definition of neighborhood. As mentioned above, Stemberger (1993) demonstrated that vowel change irregular verbs are less likely to be erroneously suffixed when the past tense form contains a “dominant” vowel (as defined by factors such as underspecification, addition bias and frequency, e.g., */o/* as in *ride* → *rode*) compared to when the dominant vowel is in the base or stem form (e.g., */o/* as in *throw* → *threw*). Because dominant vowels represent a more “optimal” phonological form, verbs whose past tenses have a dominant vowel are more easily produced and hence, should be more resistant to suffixation than those in which the dominant vowel is in the stem (and overregularized) form.

To summarize, both single- and dual-mechanism models suppose that frequency impacts error rates and that phonological features and neighborhood factors influence the production of irregularization errors like zero-marking. However, dual-mechanism models predict that regularization errors should occur independently of neighborhood similarity, whereas, a single-mechanism view proposes that similar mechanisms underlie the production of both regularization and irregularization errors. Crucially, irregular verbs that are similar to suffixed verbs should be more vulnerable to regularizations than those that are not. This latter view further suggests that error patterns will be best captured in terms of the convergence across sets of item-level predictors, leading to a characterization of items along a continuum of being more or less “at risk” for erroneous production.

**METHOD**

**Participants**

A total of 74 children participated, aged 3;8 to 13;5 years (M = 7;6 years). Children were recruited voluntarily through parent solicitation at predominately caucasian pre- and elementary schools in the San Diego, California area. All children were reported to be developing normally, and to not have substantive exposure to a language other than English.
Procedure

As part of a larger battery, each child was administered a picture-book past tense elicited production task, modified from Bybee and Slobin (1982). Seated individually with the experimenter, each child looked at pictures depicting everyday activities and told the experimenter “what happened yesterday.” For example, the child was shown a picture of a boy walking down a street. The experimenter prompted the child by saying: “This boy is walking. He walks everyday. Yesterday, he ________?” If the child used a verb other than the one provided in the prompt (e.g., “the boy ran far”), the experimenter prompted with the phrase “Can you use the same word as I do?” If the child did not do so on the second opportunity, the experimenter went on to the next item. Noncontingent supportive praise was provided regardless of the grammaticality or pronunciation of the child’s responses (e.g., “good job!”). Two practice items were administered and the child was given an opportunity to ask questions, if necessary. All children caught on to the task quickly and required little or no further explanation. Responses were audio-tape-recorded and transcribed later.

Items

A lexicon of 1191 monosyllabic English verbs was compiled from databases of adult and child vocabularies, including Kucera and Francis (1967) and Hall, Nagy, and Linn (1984). This list represents a near-exhaustive compilation of all monosyllabic verbs in current usage in everyday American English. The list consisted of 1049 regulars and 142 irregulars (25 zero-marking, 82 vowel change, 25 blends, and 10 miscellaneous). Forty-four verbs were listed either as having more than one acceptable past tense form (e.g., sneaked vs. snuck) or were considered to be homophones representing two different American English verbs each with a different acceptable past tense form (e.g., “to brake a car” (braked) vs. “to break a vase” (broke)). In these cases, each stem-past tense pairing was listed as a separate item in the lexicon.

Fifty verbs were chosen for use in the elicited production task. All verbs were likely to be familiar to children and were depictable in a black-and-white picture. Verbs were regular (suffixed with /ed/) (n = 12) or irregular (n = 38) (zero-marking, e.g., hit → hit; vowel change, e.g., ring → rang; blend, feel → felt; consonant-change, build → built) based on the type of mapping that they legitimately undergo in standard American English. Two homophonous items that could be either regular or irregular were depicted in their most frequent sense as irregulars (fly as in “yesterday, the bird, _______” (flew) and break as in “yesterday, the glass ________” (broke)). One item was later eliminated (shred) because coders disagreed with its original classification as a regular (i.e., shredded and shred were both considered to be acceptable past tense forms), leaving a total of 49 items (11 regular, 38 irregular). Thus, all items had one acceptable past tense form in American English in the pictorial and sentential context in which they were presented. Irregular and regular verbs were coded in terms of three item characteristics: (1) past tense form frequency, (2) stem and past tense phonology, and (3) past tense neighborhood structure. Tables 1a and 1b provide a summary listing for each item in terms of these features.
table 1a
characteristics of 38 English irregular verbs

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Frequency:

Information about frequency of occurrence in input to children was taken from Hall, Nagy, and Linn (1984) based on the adult speech samples for the white middle-class groups. The verbs used in the elicitation task were grouped as either above the median in past tense form frequency (High Frequency, n = 19 irregulars, 5 regulars) or at or below the median in past tense form frequency (Low Frequency, n = 19 irregulars, 6 regulars).
### Phonology:
Irregular verbs were coded following the vowel dominance criteria outlined in Stemberger (1993). In particular, verbs in the vowel change subclass were coded as Base Dominant if the stem (i.e., base form) contains a dominant vowel ($n = 18$). Vowel change verbs were Past Dominant if a dominant vowel is contained in the past tense form ($n = 7$). Irregular verbs in the zero-marking and blend sub-classes were coded as neither base nor past tense dominant ($n = 13$).

Items were also defined as alveolar ($n = 19$ irregulars, 3 regulars) or nonalveolar ($n = 19$ irregular, 8 regulars) depending on the presence of /t/ or /d/ in the final position in the stem form.

### Neighborhood structure:
Past tense neighborhoods were constructed for each phonologically-encoded stem form in the monosyllabic verb lexicon. As mentioned above, phonological neighbors are defined as stems which share a stem-final vowel or vowel-consonant phoneme combination and which vary only in initial consonant or consonant-cluster. Two aspects of neighborhood structure are evaluated here.

First, for each stem listed in the master lexicon, we counted the number of friends as the total number of neighbors listed in the master lexicon which were similar in both stem and past tense form (e.g., throw → threw and blow → blew but not mow → mowed). Verbs with two alternative past tense forms were counted as 0.5 (i.e., each alternative was “half-a-friend” to each sub-category of mappings). Regular and irregular verbs used in the elicitation task were classified based on the median number of friends: High Friends ($n = 21$ irregulars, 6 regulars) and Low Friends ($n = 17$ irregulars, 5 regulars).

Second, items used in the elicitation task were grouped according to total number of enemies in their master lexicon neighborhood (e.g., throw → threw and mow → mowed): High Enemies ($n = 19$ irregulars, 4 regulars) and Low Enemies ($n = 19$ irregulars, 7 regulars). We also subgrouped verbs based on the number of their enemies which underwent a particular type of mapping. Irregular verbs were grouped into those with larger than median number of suffixed enemies (High Suffixed Enemies, $n = 19$ irregulars) versus

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<td>lean</td>
<td>low</td>
<td>low</td>
<td>low</td>
<td>No</td>
</tr>
<tr>
<td>match</td>
<td>low</td>
<td>low</td>
<td>low</td>
<td>No</td>
</tr>
<tr>
<td>seat</td>
<td>low</td>
<td>low</td>
<td>low</td>
<td>Yes</td>
</tr>
<tr>
<td>mend</td>
<td>low</td>
<td>low</td>
<td>high</td>
<td>Yes</td>
</tr>
<tr>
<td>flow</td>
<td>low</td>
<td>high</td>
<td>high</td>
<td>No</td>
</tr>
<tr>
<td>peel</td>
<td>low</td>
<td>high</td>
<td>high</td>
<td>No</td>
</tr>
</tbody>
</table>
smaller than median number of suffixed enemies (Low Suffixed Enemies, n = 19 irregulars). Analogous groupings of stems based on number of zero-marking enemies were not constructed due to the fact that only three verbs, eat, meet, sit, belonged to neighborhoods including any zero-marked past tense forms.

Scoring and Data Reduction

All responses were orthographically transcribed and coded by a minimum of two research assistants. All discrepancies were resolved by the author. When more than one response was provided (i.e., self-corrections), only final responses were coded. Responses were coded as correct, nonvalid or errors. Correct responses were those in which the child provided the appropriate simple past tense form currently accepted in colloquial American English. Nonresponses (e.g., “I don’t know”), responses in the simple present tense (e.g., “he walks”) past or present progressive (e.g., “he was walking”), or past participle forms (e.g., “had walked,” with or without auxiliary, e.g., “rung”) were coded as nonvalid. These responses are correct, but cannot be unambiguously seen as legitimate attempts to produce verb forms in the simple past tense. Our main focus is on valid past tense errors codable in one of the following categories: Sufffixation (stem + suffix or past + suffix), Zero-marking (response is identical to the stem form), and Vowel change (erroneous change of internal vowel with no suffix). Sufffixations were scored only for the 38 irregular verbs. Zero-marking errors were possible on 42 regular and irregular non-zero-marking verbs. Vowel change errors were possible on all items.

RESULTS

Developmental Trends in Past Tense Production

Of 49 opportunities, children produced a form that could be interpreted as some type of attempt at the simple past on most trials (94.9%). Nonvalid responses (nonresponses, present tenses, progressives, etc.) were sometimes produced, but most responses were codable as legitimate attempts at simple past tense forms.

Past tense errors comprised approximately 20% of valid responses ($M = 21.7\%$, range $= 0$ to 67%), yielding an error rate that is somewhat higher than that observed in naturalistic reports. The production of past tense errors was a pervasive phenomenon, with only one child (7 years, 6 months) producing all 49 past tense forms correctly. Overall error rate decreased with chronological age ($r(73)= -.68, p < .001$).

Across children, errors were most likely to result from adding a suffix to an irregular verb ($M = 50.9\%$ of errors produced). Other errors included inappropriate zero-markings ($M = 29.0\%$) and vowel changes ($M = 20.6\%$). Both of these types of irregularization errors occurred with regular and irregular stems. The proportion of errors that were zero-markings was uncorrelated with chronological age ($r(73)= -.03, ns.$) suggesting that zero-markings were equally likely to comprise a child’s repertoire of past tense errors across the age period. In contrast, errors that were classified as erroneous vowel changes increased in rel-
ative proportion \((r(73) = +.65, p < .0001)\) while suffixations decreased \((r(73) = -.53, p < .0001)\) across age.

Individual patterns of performance indicated that children were likely to produce at least one instance of two \((n = 34)\) or three different error types \((n = 34)\). Only 5 children were single error-type producers. Consistent with the general trends reported above, younger children’s errors were likely to be suffixations and zero-markings (but not vowel changes). Children who produced any vowel change errors were all at least 7 years of age or older \((M = 8 \text{ years, 3 months})\). A closer look revealed that vowel change errors resulted primarily (although not exclusively) from the response sat to the target verb seat (e.g., “the waiter seats people at the restaurant. Yesterday, he ____”). This response may have occurred because the children confused this verb with another irregular verb sit. Because of this potential misinterpretation, the item seat is omitted from all subsequent analyses.

Based on this short review, it is clear that these children understood that they should produce some version of a simple past tense form, doing so appropriately on most occasions. At the same time, children typically produced at least some past tense errors, although they became more proficient at correct production with age. Errors were likely to be “classic” overgeneralizations of the suffix to irregular verbs. Yet, several other types of errors occurred, indicating that overregularization represents only a portion of the productivity with English past tense inflectional morphology that was demonstrated by these children.

Item Vulnerability

We turn now to analyses of which regular and irregular verbs were the most vulnerable to the different types of errors, focusing on the two most frequent error types, suffixations and zero-markings. All items and their corresponding number of suffixations, zero-markings, and vowel-changes are listed in Tables 2a and 2b. Only 1 item was produced correctly by all children (try).

Erroneous suffixations on irregular verbs.

All irregular verbs were erroneously suffixed on at least one occasion, with a mean number of suffixation errors per item of 9.3 \((Mdn = 8.0; \text{ range } = 2-27)\). Although children were producing most irregular verbs correctly on most occasions, suffixation errors were pervasive both across children and across a range of irregular verbs. Of course, some irregular verbs were erroneously suffixed quite often (e.g., catch (22) shed (27)) while others rarely were (e.g., put (2), eat (2)).

Looking first at specific phonological attributes of individual verbs, irregular verbs that ended in an alveolar were equally likely to be erroneously suffixed \((M = 8.7)\) as those that did not \((M = 9.8)\) \((F(1,36) = 0.27, ns)\). However, consistent with Stemberger (1993), number of suffixations did depend on vowel dominance in the 25 vowel change verbs for which this feature is relevant. Figure 2 overviews this effect evaluated in a 2 \(\times\) 2 repeated measures analysis of variance design with vowel dominance (stem versus past tense dominant) and past tense form frequency (high versus low) as within-item factors. High frequency
stems were less likely to be suffixed than low frequency items \( (F(1,21) = 5.5, p < .03) \) and vowel change stems with dominant vowels were more likely to be suffixed than stems whose past tense forms contained a more "optimal" vowel-consonant sequence \( (F(1,21) = 4.7, p < .05) \). Figure 2 illustrates that the impact of vowel dominance was similar for both high and low frequency verbs, reflected in a nonsignificant frequency by vowel dominance interaction.

Turning to neighborhood structure, number of suffixations was evaluated in a \( 2 \times 2 \times 2 \) repeated measures design with three within-item factors: past tense frequency (High vs.

---

**TABLE 2a.**

<table>
<thead>
<tr>
<th>Item</th>
<th>Suffix</th>
<th>Vowel + Suffix</th>
<th>Vowel Change</th>
<th>Zero-Marking</th>
<th>Total Errors</th>
</tr>
</thead>
<tbody>
<tr>
<td>eat</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>9</td>
<td>11</td>
</tr>
<tr>
<td>find</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>write</td>
<td>7</td>
<td>0</td>
<td>3</td>
<td>3</td>
<td>13</td>
</tr>
<tr>
<td>bite</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>7</td>
<td>10</td>
</tr>
<tr>
<td>cut</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>--</td>
<td>4</td>
</tr>
<tr>
<td>hit</td>
<td>8</td>
<td>0</td>
<td>1</td>
<td>--</td>
<td>9</td>
</tr>
<tr>
<td>hurt</td>
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<td>--</td>
<td>3</td>
</tr>
<tr>
<td>meet</td>
<td>8</td>
<td>0</td>
<td>0</td>
<td>7</td>
<td>15</td>
</tr>
<tr>
<td>put</td>
<td>2</td>
<td>0</td>
<td>0</td>
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<td>2</td>
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<tr>
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<td>4</td>
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<td>0</td>
<td>1</td>
<td>4</td>
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<td>know</td>
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<td>0</td>
<td>0</td>
<td>1</td>
<td>7</td>
</tr>
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<td>0</td>
<td>12</td>
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<td>3</td>
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<td>9</td>
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<tr>
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<tr>
<td>throw</td>
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<td>ride</td>
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<td>0</td>
<td>1</td>
<td>4</td>
<td>11</td>
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<tr>
<td>beat</td>
<td>8</td>
<td>0</td>
<td>0</td>
<td>--</td>
<td>8</td>
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<td>9</td>
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<td>1</td>
<td>0</td>
<td>3</td>
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<td>8</td>
<td>29</td>
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<td>16</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>19</td>
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<tr>
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<td>5</td>
<td>1</td>
<td>0</td>
<td>5</td>
<td>11</td>
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<tr>
<td>blow</td>
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<td>0</td>
<td>4</td>
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<td>2</td>
<td>24</td>
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<td>10</td>
<td>19</td>
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<tr>
<td>feel</td>
<td>15</td>
<td>0</td>
<td>0</td>
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<td>0</td>
<td>9</td>
<td>28</td>
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<tr>
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<td>0</td>
<td>0</td>
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<td>11</td>
<td>0</td>
<td>0</td>
<td>--</td>
<td>11</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>345</strong></td>
<td><strong>7</strong></td>
<td><strong>7</strong></td>
<td><strong>121</strong></td>
<td><strong>480</strong></td>
</tr>
</tbody>
</table>
### TABLE 2b.
**Errors on Regular verbs.**

<table>
<thead>
<tr>
<th>Item</th>
<th>Zero-Marking</th>
<th>VC/Blends</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>melt</td>
<td>18</td>
<td>0</td>
<td>18</td>
</tr>
<tr>
<td>pick</td>
<td>2</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>spell</td>
<td>2</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>try</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>bake</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>lean</td>
<td>3</td>
<td>6</td>
<td>9</td>
</tr>
<tr>
<td>match</td>
<td>2</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>seat*</td>
<td>10</td>
<td>36</td>
<td>46</td>
</tr>
<tr>
<td>flow</td>
<td>0</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>mend</td>
<td>16</td>
<td>0</td>
<td>16</td>
</tr>
<tr>
<td>peel</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>55</strong></td>
<td><strong>49</strong></td>
<td><strong>104</strong></td>
</tr>
</tbody>
</table>

*Eliminated from item analyses.

Low), number of friends (High vs. Low), and number of suffixed enemies (High vs. Low). All irregular verbs were included in the analysis. Figure 3 presents number of suffixation errors as a function of these three factors, graphed as main effects. Two factors were statistically reliable. Verbs with frequent past tense forms were less likely to be erroneously suffixed than low frequency items \(F(1,30) = 14.9, p < .001\). Items with many suffixed neighbors were more likely to be suffixed than those with fewer suffixed neighbors \(F(1,30) = 5.7, p < .03\). No interaction effects were observed.

![Figure 2. Suffixation errors as a function of item past tense frequency and vowel dominance.](image)
To rule out the possibility that irregular verbs with many suffixed neighbors may be more subject to suffxation simply because they live in crowded neighborhoods, regardless of whether their neighbors are regular or irregular, the above analysis was repeated substituting the number of enemies for number of suffixed enemies. A 2 (high vs. low frequency) × 2 (high vs. low friends) × 2 (high vs. low total enemies) repeated measures analysis of variance indicated that frequency was the only reliable predictor of number of suffxations ($F_{1,130} = 12.8, p < .001$). Suffxation errors were equally likely on verbs with a high ($M = 8.7$) vs. low ($M = 9.8$) total number of enemies. Thus, the enemy effects reported above are not an artifact of a general feature of neighborhood structure, but are instead likely to reflect increases in the opportunity for interference among similarly sounding items.

Within a constraint satisfaction view, similarity to suffxed enemies pushes the system toward a suffxed response, but does not absolutely guarantee erroneous production. For example, even if similarity increases the tendency for one response pattern over another, this effect may be reduced or enhanced by factors such as frequency. These kinds of convergent and competitive effects are observed here. Low frequency verbs, in general, are more likely to be erroneously suffxed, yet low frequency verbs that also have many suffxed neighbors are worse off ($M = 14.8, n = 10$) than low frequency verbs that are not subject to interference effects ($M = 9.8, n = 9$) ($t(17) = 1.83, p < .04$). The effect of similarity is somewhat mitigated in high frequency items, but not completely wiped out. High frequency verbs that belonged to neighborhoods containing few suffxed enemies were erroneously suffxed the least often overall ($M = 4.8, n = 10$), less so than high frequency verbs with many suffxed enemies ($M = 7.4, n = 9$). Thus, both factors make their own contribution to the tendency for suffxation error.
Taking this analysis one step further, irregular verbs can be placed along a continuum of more protected or more vulnerable to suffixation with respect to the three factors under consideration. That is, an irregular verb should be most likely to be overregularized if: (a) its past tense form is low frequency, and (b) its stem is similar to several legitimately suffixed verbs, and (c) its stem form contains a dominant vowel. Some verbs do not possess any of these features (n = 3) and should be the least likely to undergo erroneous suffixation (No Risk). Irregular verbs for which only one (At-Risk:1, n = 11) or two (At-Risk:2, n = 14) of these conditions are met still have some basis upon which to override the tendency for erroneous suffixation. Ten irregular verbs are the least protected from error, being pressured toward suffixation with respect to all three factors (At-Risk:3).

Figure 4 presents a significant relationship between this general index of item vulnerability and number of suffixations for irregular verbs. Post-hoc comparisons with a Newman-Keuls correction indicated that while irregular verbs with no or only one risk factor were erroneously suffixed to the same low level, tipping the scales just one notch beyond this level significantly increased the chances for error (p < .05). Importantly, when all three factors were working in tandem, items in the At-Risk:3 category were significantly more likely to be suffixed than items in any of the other groups (p < .05).

To summarize, these data demonstrate a clear role for item-level phonological factors in children's overregularizations of irregular verbs. Verbs with low frequency past tense forms were more vulnerable to error, presumably because these forms are less likely to be successfully computed by the network. At the same time, irregular verbs that sound like regular ones were more likely to be erroneously suffixed than verbs for which there were
fewer opportunities for interference from regular enemies. Vowel dominance was also a factor in increasing or decreasing the tendency for suffixation. More generally, these results suggest that accounts of "classic" overregularizations of irregular verbs should incorporate mechanisms which are sensitive to competitive and convergent effects among at least these three factors.

If this is the case, we should also be able to demonstrate that a similar set of factors facilitates the correct use of verbs that are supposed to be suffixed, that is, regular verbs. Although there are a small number of regular verbs included in the task used here, response patterns offer support for this proposal. Low frequency regular verbs are less likely to be produced correctly ($M = 6.6$ total errors) than high frequency regular verbs ($M = 5.0$), and regular verbs belonging to neighborhoods with many other regular friends are more likely to be produced correctly ($M = 2.0$ errors) than regular verbs from less friendly neighborhoods ($M = 9.5$ errors). Furthermore, similarity to other regular verbs facilitates correct production for both high ($M = 1.3$ vs. $10.5$ total errors) and low frequency regular verbs ($M = 3.0$ vs. $9.0$ total errors). Taken together, these findings are consistent with the view that item-level phonologically-based factors impact children's tendency to produce overregularizations of irregular verbs, as well as work to ensure that regular verbs will be successfully produced in their correct suffixed form.

**Zero-marking.**

Zero-marking errors occurred on at least one occasion for 88.1% of the items (37 of 42). Note in Tables 1a and 1b that some verbs were frequently zero-marked (e.g., *melt* (18), *make* (12)), while others rarely were (e.g., *know* (1), *fall* (1)). On average, zero-marking occurred approximately 4.1 times per stem, with a median of 3.0 (range = 0–18).

Zero-marking errors were more likely on alveolar stems, regardless of verb class. Evaluated in a 2 x 2 repeated measures analysis of variance with stem-final phonology (alveolar vs. nonalveolar) and verb class (regular vs. irregular) as within-item factors, there was a main effect of phonology ($M = 2.0$ vs. $8.0$; $F(1,37) = 91.1, p < .0001$), class, $F(1,37) = 21.3, p < .0001$), as well as a class x phonology interaction $F(1,37) = 29, p < .0001$). Both regular and irregular verbs with stem-final alveolars were significantly more likely to be zero-marked than nonalveolars ($M = 17.0$ vs. 1.4 for regulars; $M = 6.5$ vs. 2.3 for irregulars), although this effect is more exaggerated in regular stems. These results are consistent with the expectation that zero-marking occurs by analogy to items that share a phonological shape with legitimately zero-marked forms, regardless of verb class. Indeed, all of the verbs ($n = 3$ irregulars, $n = 2$ regulars) that were never erroneously zero-marked ended in a consonant other than /t/ or /d/.

Although Stemberger (1993) restricted his discussion to the relationship between vowel dominance and erroneous suffixation, stem-dominance should also make a verb more vulnerable to zero-marking errors. Number of zero-marking errors on 25 vowel change irregular verbs was analyzed in a 2 x 2 repeated measures analysis of variance design with vowel dominance (stem versus past) and stem-final phonology (alveolar vs. nonalveolar) as within-item factors. Results indicate that both factors were reliable predictors (alveolar: $F(1,21) = 29.3, p < .0001$; vowel dominance: $F(1,21) = 4.6, p < .05$). A higher order inter-
action was not observed. To illustrate, vowel change verbs which ended in an alveolar consonant and were stem dominant were most likely to be zero-marked ($M = 6.8$), more so than past dominant alveolars ($M = 4.8$). Nonalveolars that were stem dominant were zero-marked more often ($M = 2.1$) than verbs that were not vulnerable to zero-marking in terms of either of these factors. Nonalveolar past dominant verbs were zero-marked the least often ($M = 0.7$). Again, we see the independent contribution of each factor.

At the same time, 22 (of 27) nonalveolar stems were zero-marked on at least one occasion, as were 6 (of 7) past dominant stems (2 of which were also nonalveolar). It is clear that these phonological features play off of each other, each pushing the system toward a zero-marked response. Yet, exceptions exist. Is there a role for neighborhood factors to account for zero-marking when a verb lacks key phonological features?

Number of zero-marking errors was analyzed in $2 \times 2 \times 2$ repeated measures design with frequency (high vs. low), friends (high vs. low) and enemies (high vs. low) as within-item factors. All eligible regular and irregular verbs were included in the analysis. Only the main effect of friends was statistically reliable ($F(1,33) = 4.8, \ p < .04$), with no interactions. Items that belonged to friendly neighborhoods were less likely to be zero-marked than items with fewer friends ($M = 2.7$ vs. $5.7$). This trend was observed for items that both did ($M = 6.2$ vs. 9.4) and did not end in a stem-final alveolar ($M = 1.5$ vs. 2.8), as well as both stem ($M = 2.8$ vs. 6.0) and past dominant verbs ($M = 2.3$ vs. 4.0). While there is an uneven distribution of items in these subcategories suggesting a cautious interpretation, these patterns do implicate a role for neighborhood structure in determining zero-marking in some cases.

To summarize, regular and irregular stems that were most likely to undergo erroneous zero-marking ended in an alveolar consonant and/or contained a dominant vowel in their stem. These error patterns indicated that item-level phonological information is a strong predictor of zero-marking, regardless of whether the verb is typically associated with the regular or an irregular mapping class. In the context of this elicitation paradigm, these children were clearly using zero-marking productively with respect to key phonological features, and not simply leaving these forms unmarked because they were “not trying to convert the verb to a past tense form at all” (Xu & Pinker, 1995, p. 537). At the same time, both regular and irregular verbs were sometimes zero-marked even when these phonological features were absent. A complete picture of zero-marking errors was best framed in terms of competing and convergent pressures from several sources.

**DISCUSSION**

In this study, pre- and elementary school children were asked to report “what happened yesterday” using common English regular and irregular verbs. Children demonstrated considerable expertise with the English simple past tense system, producing fewer than 20% errors. At the same time, most speakers made at least a few mistakes, even children well into the school-aged years. Children’s productions reflected both regular and irregular patterns, including zero-markings, vowel-changes and blends, indicating that the ability to be productive with the past tense system was not simply limited to “classic” overregularizations of irregular verbs.
Both suffixation and zero-marking errors were predicted by sets of item-based properties that worked in tandem to reduce or enhance chances for certain responses. Erroneous suffixations were most likely to occur on irregular verbs with low frequency past tenses, verbs with dominant vowels in their stem (rather than past tense) forms, and verbs with many suffixed neighbors. Irregular verbs that were vulnerable to error with respect to all three of these factors were the most likely to be overregularized. Zero-marking errors were the most frequent when a regular or an irregular stem ended in an alveolar consonant and/or when the stem was more easily generated because of vowel dominance factors. Neighborhood structure also played a role when these phonological features were absent.

The factors pushing children toward regularization and irregularization were similar in two key ways. First, phonological information influenced the production of both types of errors, defined in terms of specific attributes of stems and past tenses, as well as patterns of similarity across a phonologically-defined lexicon. These were observed to operate independently of verb class, in that both regular and irregular verbs were zero-marked when certain conditions were met. Marchman et al. (1996) report similar findings based on a different set of children and an item set that included a more balanced distribution of regular and irregular English verbs. Thus, the pattern of findings reported here is not likely to be an artifact of the particular items chosen for use in this study.

Second, in some cases, verbs were vulnerable to both regularization and irregularization errors when the appropriate past tense forms were not readily available to the speaker (as indexed by frequency and neighborhood factors). In this sense, zero-marking, like suffixation, acted in a default manner, applied in the absence of any specific phonological characteristics that would drive response-by-analogy. This interpretation has implications for accounts of the conditions under which default generalization can arise in single mechanism systems (e.g., Hare, Elman, & Daugherty, 1995; Plunkett & Nakisa, in press) and may be useful in explanations of the overuse of zero-marking that is a hallmark feature in children with specific language impairment (Bishop, 1994; Loeb & Leonard, 1991; Marchman et al. 1996; Rice & Oetting, 1993).

In general, these findings run counter to those supporting a dual-mechanism or "hybrid" view where phonological similarity is only relevant for the production of irregular forms and only suffixation applies as a symbolically-driven default process (c.g., Prasada & Pinker, 1993). We suspect that discrepancies between the data reported here and previous findings derive from details of the definitions of the phonological neighborhoods and/or the various experimental paradigms employed. In our view, the elicitation task used here proved to be a sensitive and fruitful means of identifying systematicities in children's productive use of regular and irregular past tense morphology that may not be evident using other techniques.

Analogous results have been reported for adult speakers of English (Marchman & Callan, 1995) and another sample of children using a different item set (Marchman et al., 1996). Furthermore, these patterns are consistent with the behavior of connectionist simulations of the acquisition of this inflectional system (Daugherty & Seidenberg, 1992; Marchman & Callan, 1995; Plunkett & Marchman, 1993; Rumelhart & McClelland, 1987). These findings are also compatible with frequency and neighborhood consistency effects.
that have been observed in English speakers’ processing of spelling-sound correspondences during word naming (e.g., Jared et al., 1990; Plaut, McClelland, Scidenberg, & Patterson, 1996; Seidenberg & McClelland, 1989). Such effects typically take the form of “frequency by regularity” interactions, indicating that item frequency can override similarity, yielding effects that are more evident in low frequency items. A role for phonological similarity was observed here in both high and low frequency items, although it was somewhat less robust in high frequency items in some cases. A lack of strong interaction patterns is likely due to the use of error rates rather than response latencies and the fact that our speakers spanned a wide age range and developmental level. Nevertheless, both word naming and past tense findings are consistent with the conclusion that the mechanisms underlying the productive use of regular and irregular patterns are actually more similar than they are different.

We briefly return to the fact that number of friends was not significantly related to the frequency of suffixation errors on irregular verb stems. This finding is puzzling given that both the single- and dual-mechanism models predict that the support of the irregular cluster (i.e., number of friends) should reduce vulnerability to suffixation. We can suggest at least two possible reasons for this result. First, even though reliable neighborhood effects were found, it is possible that our definitions of “neighborhood” or “friend” did not capture some of the appropriate within-cluster features that work to facilitate successful production in children in this age range. Clearly, other factors might be relevant to the organization of the past tense inflectional system in English, for example, initial consonant (Bybee & Moder, 1983). Second, the impact of friends may have been masked by restricting our analysis to only suffixation errors. If friends facilitate individual item processing, we might expect that this factor would be an index of the tendency to be produced erroneously in general, not just as a suffixed response. There is evidence that this is the case. Verbs with friendlier neighborhoods were more likely to be produced correctly overall ($r = +0.33, p < .01$).

Although suffixations and zero-markings were the most common error types produced by these children, vowel change errors comprised an increasing proportion of errors produced by older children. These data are consistent with general trends seen in both psycholinguistic and modeling data. Based on data from an on-line task, Marchman & Callan (1995) reported that almost 40% of adults’ past tense errors were classified as vowel change, blends, or zero-marking, although all types of errors occurred. Marchman (1993) noted that connectionist networks trained to map phonological encodings of stems and past tense forms were most likely to add a suffix or zero-mark novel forms early in training, whereas, vowel changes and blendings characterized the later periods of training. In the network, this is attributable to features of the vocabulary to which the network is exposed. Suffixation is reflected in the largest number of items and is a best statistical “first guess” when the goal is to minimize error on the output. As training continues, the network picks up on more locally defined patterns, using phonological cues to mapping type which are characteristic of a smaller but often more frequently seen portion of the training set.

Connectionist models provide useful insights into the possible factors which might be relevant over the course of the acquisition of a system like the English past tense, as well as several other cognitive and linguistic domains (see Elman et al., 1996 for a recent
review). However, we should emphasize that the current findings focus on a particularly "English" class of solutions to learning inflectional morphology. The same set of factors interact in substantially different ways in domains that are as similar as the English plural and past tense (Marchman, Plunkett, & Goodman, 1997; cf. Marcus, 1995). Several recent studies have moved beyond the past tense to explore the set of configurations that are and are not possible across the world's languages (Bybee, 1995; Clahsen, Rothweiler, Woest, & Marcus, 1992; Hare et al., 1995; Marcus et al., 1993; Plunkett & Nakisa, in press).

In conclusion, although most children produced at least some past tense errors, even our youngest children generated correct English regular and irregular past tense forms most of the time. Thus, the system "works" on most occasions. Fortunately, errors that do occur reveal substantive information regarding the basis for children's abstraction and organization of regularities and subregularities. In our view, rather than a system of specialized grammatical-rule-based mechanisms and representational formats, children's ability to be productive with English past tense morphology is best seen as the result of a complex interplay of features that necessarily must compete and converge during language use. It is tempting to further speculate that the sorts of complexities which derive from item-based competitions within a phonologically-based lexicon may end up being the core of what is truly interesting about the hallmark human ability to go beyond the input.

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NOTES

1. In the case hit, all of the enemies which undergo suffixation are homophonous with zero-marking alternatives, yielding two acceptable past tense forms (e.g., fit → fit and fit → fitted). Each alternative is counted as 0.5 in the tabulation of number of friends and enemies.

2. We can nevertheless point out that this "misinterpretation" was more frequent in the older age groups and may reflect a legitimate developmental trend. Younger children were more likely than older children to feel comfortable with the correct regular form seated, rather than sat.

3. Items coded as stem (base) dominant as well as those in the blend and zero-marking subclasses were considered "at risk" with respect to this feature (i.e., their past tense forms did not contain a dominant vowel).

REFERENCES


