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Multiple determinants of the productive use of the regular past tense suffix

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Abstract

We offer evidence that the productive use of English regular past tense morphology (e.g., *drived*) results from competitions among lexical-level features within a single mechanism associative system. We present error data from: (1) on-line elicited productions by adult native speakers (N = 51), and (2) connectionist back-propagation networks trained to map stems and past tenses of 552 English verbs. The frequency of regularizations is analyzed in terms of item frequency, stem final alveolar consonant, and similarity in past tense mapping across "friends" and "enemies" in phonologically defined neighborhoods. All items were compiled from a lexicon of 1,191 verbs which represents a near-exhaustive listing of monosyllabic stem-past tense pairs in current American English. Results revealed striking similarities between the human and simulation data. Regularizations were significantly correlated with item frequency, as well as phonological attributes of the stem. Crucially, regularization was a function of phonological similarity to frequent suffixed items, especially for irregulars that normally undergo a vowel-change. These results are incompatible with the view that regularization applies by default, independently of inter-item similarities which support the acquisition and processing of lexical items in associative systems.

Introduction

The productive use of patterns abstracted from English regular (e.g., *quit => quitted*) and irregular (e.g., *flow => flew*) verbs has become a fertile testing ground for models of language acquisition and processing (e.g., Daugherty & Seidenberg, 1992; Marchman & Bates, 1994; Marcus, Ullman, Pinker, Hollander, Rosen, & Xu, 1992). One central issue revolves around the claim that regular morphology involves rule-governed mechanisms that are distinct from those used in the processing and acquisition of individual lexical items (e.g., Marcus, et al., 1992; Pinker & Prince, 1988). In dual-mechanism models, regularly inflected forms are produced via concatenation which joins stem and suffix in a default fashion regardless of item-level features. Irregular stems and past tenses, in contrast, including zero-marking (e.g., *hit => hit*), vowel change (e.g., *ring => rang*) and miscellaneous (e.g., *go => went*) mapping sub-types do not adhere to the suffixation pattern and are stored as pairs often in "clusters" of similarly sounding neighbors (i.e., "friends"). These features determine the ease with which an irregular is accessed and the susceptibility of other forms to "irregularization." This model is supported by apparent dissociations between regular and irregular forms, for example, the processing of regulars is less sensitive to item frequency than irregulars and judgments of "goodness" are a function of similarity between neighbors of irregulars (but not regulars) (e.g., Prasada & Pinker, 1993).

Single mechanism models, in contrast, propose that the production of regularizations as well as irregularizations are governed by similar sets of item-level factors processed within a single associative system (Daugherty & Seidenberg, 1992; MacWhinney & Leinbach, 1991; Rumelhart & McClelland, 1987; Plunkett & Marchman, 1991, 1993). These models are typically grounded in connectionist architectures which exploit distributed encodings to select among competitors within and across all types of conflicting mappings.

Both dual- and single-mechanism models are consistent with findings that children's past tense regularizations are more frequent with stems that are low frequency (Marcus, et al., 1992) and that possess certain phonological features, such as a stem final alveolar consonant (Bybee & Slobin, 1982) or a non-"dominant" vowel (Stemberger, 1993). However, Marchman (1994) showed that inter-item similarity was <u>also</u> important in predicting the frequency of regularization errors produced by children in an elicited production task. In that study, item frequency, phonological features, <u>and</u> similarity to a high frequency regular neighbor each contributed about the same amount of independent variance toward the prediction of which items would be regularized. No one factor was the primary determinant of error frequency. Analyses of zero marking and vowel change errors indicated that similar factors predicted an item's vulnerability to irregularization as well. Thus, in contrast to a dual-mechanism view, these results cast doubt on the need to posit a special mechanism for productivity of the regular suffix. More generally, the results suggest an outline for a common set of principles guiding productivity with both regular and irregular patterns. Analogous results have been found in studies of reading where both regular and irregular phonological-to-orthographic mappings are influenced by frequency, phonological features, as well as neighborhood structure and consistency (Jared, McRae & Seidenberg, 1990; Seidenberg & McClelland, 1989).

In this paper, we further evaluate the legitimacy of characterizing the productive use of regular past tense verbal morphology in terms of competitions among item-based factors within a single mechanism system. We present regularization data from two sources: (1) an on-line elicited production task with adult native speakers of English, and (2) connectionist back-propagation networks trained to map stems and past tenses of English monosyllabic verbs. The frequency of regularizations is analyzed in terms of item characteristics, including token frequency, presence of phonological features, and similarity across "friends" and "enemies" in phonologically defined neighborhoods. In conjunction with previous analyses (Marchman, 1994), the results suggest that productive use of both regular and irregular patterns by human speakers can be viewed as a competitive associative process similar to that implemented in connectionist single-mechanism models.

Method

On-line Elicitation Task

Subjects. Fifty-five adult native monolingual English speakers participated in the on-line elicitation task. All were students at the University of Wisconsin, Madison and received extra-credit in their Psychology courses in exchange for their participation. Four participants were omitted due to equipment malfunctions (e.g., microphone failure), yielding a final sample of 51.

Task and Procedure. The elicitation task involved producing past tense forms of familiar English verbs as they appeared in stem form on the screen of a Macintosh IIci running PsyScope (Cohen, MacWhinney, Flatt, & Provost, 1993). Each stem remained on the screen until the onset of the verbal response or 2500 msec, with 2500 msec between trials. An instruction screen reminded participants that some English verbs form their past tenses through suffixation, while others "do something different, for example, changing a vowel or nothing at all." An 8 item practice session was given. Responses were audio-taped and later transcribed. Reaction times to initiate responses were also recorded, but will not be discussed here. Speakers also participated in a naming task (not discussed) administered in a counter-balanced order across subjects.

Items. A total of 78 items were used in the on-line tasks, selected from a near-exhaustive lexicon of all monosyllabic stems and their simple past tense forms in current usage in Standard American English. This lexicon was compiled from Kucera & Francis (1967) (KF) and other text and free-speech corpora and served as the basis for estimating phonological neighborhood values (see below) for the English past tense inflectional system. Forty-four of the 1191 items in the lexicon were coded as either having more than one acceptable past tense form (e.g., *sneaked* vs. *snuck*) or as homophones (e.g., to *break* a car (*braked*) vs. to *break* a vase (*broke*)). Verbs with two acceptable forms were weighted as 0.5 in all calculations. Each item was coded for the following with reference to the complete corpus lexicon:

(1) Verb class: Items were grouped into sub-classes depending on the type of relationship that obtains between stem and past tense form: Regular (i.e., suffixed), VC/BL, Zero-marking, and Miscellaneous. The distribution of items across classes in the corpus-based lexicon is outlined in Table 1. Table 1 also shows the class distribution of the 78 items selected from this lexicon for use in the on-line task (regular: N = 40; irregular: N = 38).

(2) Token Frequency: Items were grouped based on their KF frequency values for simple past tense forms: High (N=40, M=117.6; regular: M=105.6; irregular: M=129.7) and Low (N=38 M=6.2; regular: M=6.1; irregular: M=6.3). Items were matched across the two major classes, and hence, class differences in frequency were not statistically reliable in either the low or high frequency sets.

(3) Phonology: Stems were classified as alveolar (N = 29) or non-alveolar (N = 49), defined by a /t/ or /d/ in stem-final position. Irregulars consisted of 20 alveolar and 18 non-alveolar stems. All zero-marking items are alveolar; whereas, 18 (of 29) VC/BL items are non-alveolar.

TABLE 1. Distribution of type frequency of items across class.

CLASS	CORPUS-BASED LEXICON	SIMULATION	ON-LINE
REGULAR	1049 (88.8%)	474 (85.9%)	40
VOWEL-CHANGE (VC)	82 (6.8)	42 (7.6)	22
BLEND (BL)	25 (2.1)	18 (3.3)	7
ZERO-MARKING	25 (2.1)	14 (2.5)	8
MISCELLANEOUS	10 (0.8)	4 (0.7)	1
TOTAL	1,191	552 (16,214 tokens)	78

(4) Past Tense Neighborhood Structure:

Friend Factors:

• Friends (F): Number of items in the phonological neighborhood defined by stem final vowel-consonant or vowel which undergo a similar mapping, e.g., *ring* => *rang*; *sing* => *sang*.

• Past Tense Friend Frequency (PFF): The sum of KF past tense frequencies of friends.

Enemy Factors:

• Enemies (E): Number of neighbors that undergo a different transformation in total (E-ALL) or by transformation type (E-SUFF)

• Past tense Enemy Frequency (PEF): Summed frequency of all enemies (PEF-ALL) or those that involve suffixation (PEF-SUFF).

Neighborhood Factors:

• Number Ratio: Ratio of number of friends to total number of neighbors.

• Frequency Ratio: Ratio of total friend frequency to neighborhood frequency.

Scoring and data reduction. All responses were coded as correct, error or non-valid. Only final responses were coded in the case of self-corrections. Errors were classified as regularization (stem + suffix), zero-marking (identical stem and past tense form), vowel-change (modification to vowel), blend (vowel change + suffix), or miscellaneous. Present, progressive, and participle (with or without auxiliary) forms were non-valid and omitted from analyses.

Simulation

Procedure. Ten fully interconnected networks (51 input, 45 hidden, 68 output units) were trained on mappings between stems and past tenses of English verbs using a standard back-propagation algorithm (TLEARN). All inputs and outputs were encoded with a 17-unit binary phonological feature system similar to that reported in Marchman (1993). Values for initial weights, momentum and learning rate were randomly assigned within a small range. Training used random presentation for 100 passes with item-based updating.

Training corpus and network architecture. A total of 552 English verbs were chosen for use in the simulations, representing all di- or triphonemic verb stems listed in the corpus-based lexicon. Due to architecture constraints, stems involving more than three phonemes were excluded. Stems took the form Consonant-Vowel-Consonant (CVC), CVV, VCC, VC or CV, encoded in a maximum of 51 units (17 units per phoneme). Past tense forms could include a fourth suffix phoneme (17 units), yielding an output layer length of 68 units. A set of neutral values (all 0's) was used as a place-holder for non-suffixed past tense forms or di-phonemic forms. All suffixes appeared in the far right phoneme slot. All homophones were excluded (i.e., each phonologically encoded stem had only one past tense form). Each stem was presented to the network according to KF token frequency values. Thus, the total training set included 16,214 tokens (552 verb types).

Each stem in the simulation corpus was coded for: past tense sub-class, KF token frequency, presence/absence of stem-final alveolar consonant, and past tense neighborhood structure. Neighborhood variables were calculated using the same procedures as the elicitation study, restricted to the 552 items in the training corpus. Table 1 presents the number of verb types in each class. Note that this distribution closely approximates that of the full lexicon, even though items were selected solely in terms of length in phonemes.

Scoring and data reduction. Performance was sampled at 5 intervals (6, 12, 24, 48 and 92 epochs) chosen to maximize the assessment of network performance early in training. Each output was evaluated using a "closest vector" technique on a phoneme-by-phoneme basis. In other words, an output was considered correct if it "best fit" the target for each and every phoneme in the past tense form. For errors, the actual closest fit output was evaluated against the target stem and coded as regularization, zero-marking, vowel-change, blend, or miscellaneous. All data are averaged across the 10 networks.

Results and Discussion

Frequency of Errors in Humans and Networks

As expected, adult native speakers produce the majority of past tense forms correctly in this elicitation context. Nevertheless, a total of 338 (of 3978, 8.5%) erroneous responses were recorded. The majority of these (310 of 398, 91.2%) occurred on irregular items and primarily (although not exclusively) involved the overuse of the /ed/ suffix (212 or 68.4%). Thus, although regularizations were the most common type of error, adults also produced irregularizations on both regular and irregular stems, e.g., zero-marking (31), vowel-change/blend (29), and miscellaneous (43) error types.

Table 2 outlines performance in the networks as a function of epoch of training. Note that proportion correct steadily increases over training, eventually reaching more than 93% correct (M = 6.5% errors). It is assumed that performance could continue to improve with training, yet note that levels of accuracy are strikingly similar in the human speakers and networks.

The right hand portion of Table 2 presents the proportion of erroneous responses in the four error categories. Although there is considerable variation across networks, these networks were generally likely to produce VC/BL, regularization and miscellaneous errors, while zero-marking errors were infrequent across the period. This is in contrast to the adult human speakers who overwhelmingly preferred regularizations, even though all error types occurred. Nevertheless, note also that regularizations tended to decrease, while vowel change/blend errors tended to increase over training. A similar developmental trade-off between regularizations and irregularizations has been reported for human children (Marchman, 1994).

TABLE 2. Average percent correct and proportion of error types across simulation

EPOCHS	% CORRECT	DISTRIBUTION OF ERROR TYPES			
		REGS	VC/BL	MISC.	ZERO
6	81.5% (15.6)	16.9% (26.3)	37.4% (34.0)	10.0% (16.2)	2.4% (4.4)
12	86.5 (12.3)	13.5 (23.3)	42.7 (37.8)	8.8 (15.1)	1.7 (3.7)
24	90.0 (8.5)	11.7 (22.5)	44.6 (39.7)	8.9 (17.5)	1.4 (3.7)
48	92.4 (6.6)	6.4 (15.0)	49.9 (41.2)	9.5 (17.5)	0.9 (3.4)
96	93.5 (6.2)	4.1 (11.9)	50.5 (43.2)	11.3 (23.3)	0.8 (3.6)
MEAN (sd)	**88.8** (11.3)	**10.5** (20.9)	**45.1** (39.3)	**9.7** (18.0)	**1.5** (3.8)

Item Analyses: Predictors of regularization errors

We now focus on the contribution of frequency, phonological features, and neighborhood factors in predicting which irregular verbs will be vulnerable to regularization. We should first note that the vast majority of items (32 of 38, 84.2%) were subject to regularization by at least one human speaker. However, items in the zero-marking subclasses (M = 13.3) were significantly more likely to be regularized than VC/BL items (M = 2.8; (t(35)=4.9, p<.0001). That is, all 8 zero-marking items were regularized at least once; whereas, 6 of the VC/BL items (of 23, 20.7%) were not regularized by any of the human participants. This trend was also observed in the networks. VC/BL items (M = 0.006) were significantly less likely to be regularized than zero-marking items (M = 0.13 t(368)=8.9, p < .001). As we shall see, these two general classes of irregular items differ in several attributes that may contribute to this pattern.

Table 3 overviews first-order correlations between these factors and the frequency of regularizations in human speakers and the simulations for all items, as well as VC/BL vs. Zero-marking items taken separately.[1] Note first that, as predicted by both a single- and a dual-mechanism view, frequency is negatively correlated with regularization rate, accounting for approximately 18% of the variance in the human data. To illustrate, high frequency irregulars (M = 1.9) were significantly less likely to be regularized by human speakers than low frequency irregulars (M = 9.7, t(36)=3.8, p<.001). Further, the 6 items that were produced correctly by all 51 human participants (*drive, find, meet, tell, wear, write*) were all members of the high frequency set. This relationship obtains when both VC/BL and Zero-marking items are analyzed separately as well.

Token frequency is also a significant predictor in the simulations. Items that were regularized at least once by the network had a token frequency of M = 2.4, compared to those that were never regularized (M = 160.6) (t(388)=3.3, p < .0001). This relationship is less reliable for VC/BL only items (p < .07), but is quite robust among the zero-marking items. All in all, these data are generally consistent with the well-known pattern that token frequency strengthens associations and can serve to protect items from error.

As has been noted in studies with children (Bybee & Slobin, 1982; Stemberger, 1993), phonological features can also be seen to play a role in predicting regularization frequency. For example, in the human data set, frequently regularized items were more likely to be alveolar (M = 7.4) than non-alveolar (M = 3.6). However, this relationship is only marginally reliable (p < .08) and clear counter-examples exist. Indeed, 3 (of 6, 50%) items that were never regularized in the on-line task were alveolar stems, going against the general prediction. As noted above, these never-regularized items were all quite high in frequency and thus, it is perhaps not surprising that they were protected from error despite being linked with this phonological feature. Nevertheless, the role of stem-final alveolar consonants cannot be taken at face value given that the correlation between regularization rate and alveolar reverses if we restrict our analyses to VC/BL items. For these items, human speakers were less likely to regularize alveolars (M = 1.5) than non-alveolars (M = 3.6).

A similar pattern is found in the networks. Here, for all items, alveolar stems are more likely to undergo regularization (M = 0.06) than non-alveolars (M = .008) (F(1,389)=24.6, p<.001), regardless of frequency (F(1,388)=19.4, p<.001). Yet, a switch in the direction of relationship is suggested when the VC/BL items are taken separately (r = -.09, p < .08).

We can speculate that this reversal is related to an interaction between two major classes of phonological features, i.e., presence of vowel-consonant clusters and stem-final alveolar consonants. These factors, in interaction with item frequency, appear to be operating as opposing cues to mapping type. The importance of stem-internal phonological cues to past tense formation is consistent with recent findings by Stemberger (1993) who has shown that some vowel change/blend verbs are resistant to regularization because their past tense forms involve a "dominant" (i.e., easier to produce) vowel. When the dominant vowel is contained in the stem, in contrast,

[1] First-order correlations are provided for the zero-marking items to facilitate comparison to the patterns observed in the VC/BL items. However, these values should be interpreted with caution given the small number of items in this class.

regularizations are more likely because speakers are pushed toward producing the stem and hence, stem+suffix forms. Marchman (1994) has also demonstrated that vowel dominance was one of several features contributing to regularization in children's elicited productions. A complete analysis of the interactions between stem-internal and stem-final phonological attributes are beyond the scope of the current paper. Nevertheless, these findings suggest that these factors do play an important role and future studies should match items for these features.

We finally turn to a brief discussion of the role of neighborhood factors. Both single- and dual-mechanism models predict that similarity to items that undergo the same type of past tense transformation (i.e., "friends") should help to support the irregular pattern and hence, should bear a negative relationship to regularization frequency. There is some suggestion that friends offer such support here, either in terms of sum of friend frequency (PFF) or the relative frequency of friends to enemies (Frequency Ratio). However, further analyses indicate that these variables are significantly inter-correlated with item frequency, and do not make significant unique contributions in either the simulation or human data sets.

Relatively weak contributions of friend-based factors are consistent with data reported in Marchman (1994). Nevertheless, these findings are puzzling in that both single- and dual-mechanism models place considerable importance on within-neighborhood similarities in the processing of irregular forms. In light of the findings reported above, one possible explanation is that the role of friends might best be re-defined in terms of particular phonological characteristics (e.g., presence or absence of a particular vowel, stem-final alveolar, etc.), rather than similarity across items *per se*. Again, further investigation of this issue is left to future studies.

Our last set of results focuses on the role of enemy factors, representing a key point where the predictions of the single- and dual-mechanism models diverge. In the dual-mechanism model, regularization is proposed to apply by default and hence, an irregular verb's similarity to a regular verb should not make it any more vulneral regularization than any other item in need of a pasi form. In contrast, single-mechanism models pos errors of all types derive from analogies that are drawn items. Thus, the presence of regular enemies s increase the chance that a verb is regularized.

Returning to Table 3, note that there appears to b minor impact of enemies (either in total or suffixed) i the human and simulation data for all items taken to Neighborhood factors make little contribution b frequency, and possibly phonological factors, le support for a dual-mechanism view. Yet, it is puzzlir these relationships are also absent in the simulation c which the associative lexical learning mechani presumed to rely on these cross-item relationships.

However, when we restrict our analyses to VC/BL only, robust correlations emerge in both the huma simulation data. To illustrate, VC/BL items that are regularized have approximately M = 6.3 suffixed neig which have a KF frequency of 36.0. In contrast, iten are regularized have an average of 6.0 suffixed neig with a frequency of 61.3. Multiple regression an further indicate that enemy factors account for variance and beyond both item frequency (r^2 change = 15.39 .02) and presence of an alveolar consonant (r^2 cha 15.8%, $p < .02$) in the human data. Conversely, whil frequency makes its own unique contribution beyond (factors (r^2 change = 10.8%, $p < .05$), the presence alveolar consonant does not (r^2 change = 6.8%, ns). consistent with Marchman (1994), both item frequen similarity to regular neighbors make significant indep contributions to regularization frequency for h speakers. As might be expected, the simul demonstrated the impact of enemies quite strongly i sub-classes of items. These factors overrode any ef frequency or presence of an alveolar consonant in the V items. For the relatively small set of zero-marking both similarity to suffixed enemies (r^2 change = 5.19 .05) and item frequency (r^2 change = 7.5%, p · contributed unique variance.

TABLE 3. Predictors of overgeneralizations of the /ed/ suffix.

	ALL ITEMS		VC/BL		ZERO-MARKING	
Predictor	*HUMAN*	*SIM*	*HUMAN*	*SIM*	*HUMAN*	*SIM*
KF freq.	-0.39**	-0.13**	-0.44**	-0.08	-0.69	-0.36*
Alveolar	+0.25	+0.24**	-0.38*	-0.09	---	---
# Friends (F)	+0.18	+0.12*	+0.34**	-0.01	-0.13	-0.04
Σ Friend Freq. (PFF)	-0.19	-0.14**	+0.13	-0.05	-0.41	-0.27*
# Enemies (E-ALL)	-0.21	-0.16*	+0.12	+0.05	-0.32	-0.22
Σ E-ALL Frequency	+0.11	+0.02	+0.54***	+0.23**	-0.33	-0.12
# Suffix E (ESUFF)	-0.10	-0.15*	+0.20	+0.10*	-0.52	-0.18
Σ ESUFF Freq.	+0.05	+0.07	+0.48**	+0.44***	+0.31	+0.32*
Number Ratio	+0.25	+0.25**	+0.16	-0.05	-0.01	+0.09
Frequency Ratio	-0.34**	-0.18**	-0.24	-0.11*	-0.27	-0.19*

* = p < .05
** = p < .01
*** = p < .001

Conclusion

In conclusion, these studies sought to evaluate influences on the productive use of the English past tense suffix in both human speakers and connectionist simulations. In general, human speakers of English and networks trained on a lexicon of English vocabulary items produce past tense errors to about the same degree. While there are some clear differences in the types of errors that are produced, striking similarities were observed across the two sources of data regarding which items were vulnerable to error. Several previous findings were replicated, including the importance of token frequency in protecting an item from error and the complex role of phonological factors.

Most importantly, it was demonstrated that factors which capture competitions between similar-sounding items within a phonological neighborhood do indeed play a strong role in the productive usage of the English regular suffix in both networks and human speakers. These results are consistent with previous analyses using data from children, as well as recent studies in other language domains, such as visual word recognition. In general, these data support the conclusion that both regularization and irregularization are best thought to involve competitive associative processes similar to those implemented in single-mechanism connectionist networks.

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