Inflectional Morphology
and Its Interaction with Word Structure

by

John J. Kim

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Submitted to the Department of Brain and Cognitive Sciences
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ABSTRACT

Word stems that do not have irregularly inflected roots as their heads have regularly inflected forms. That this is the case even if a word stem is derived from a root with an irregularly inflected form implicates a categorical difference between regular and irregular inflection: When a word's stem is headed by a word root, that root's features, including the irregularity feature, are inherited by the stem as a whole; thus, if an irregular word root is the head of a word stem, that stem's inflected form is irregular. When a word's stem is not headed by a word root, the root's features are not inherited by the overall stem; thus, if a word stem is derived from a irregular word root but the root is not the head of the stem, then the stem's inflected form cannot be irregular, and the default regular rule categorically applies to inflect the stem.

This categorical difference between regular and irregular inflection, which depends on a word stem's grammatical structure, is apparent in adult judgments whether the stems exist or are novel, and, indeed, even if the stems are nonce words (Chapter 1), in elicited productions of school-age and pre-school children (Chapter 2), and in the online computation of inflection in a production task (Chapter 3). This structural proposal is defended against models of inflection that do not make a qualitative distinction between regular and irregular inflection, including semantic alternatives, a functionalist approach, and a certain class of connectionist models of inflection. Implications for the nature of linguistic representations, language acquisition, and processing architectures are explored.

Thesis Supervisor: Dr. Steven Pinker
Title: Professor of Cognitive Sciences

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I would like to start by thanking my committee. Steve Pinker has been instrumental in the research reported in this thesis. Without his guidance, insight and help, this thesis would not have been possible. His faith in me as a scientist was unwavering, which helped me tremendously because my own faith in me as a scientist was unsteady at best, my career being characterized by "long periods of boredom punctuated by brief moments of sheer terror" and all.

Ken Wexler knows exactly where the interesting questions lie. This I've known since I've known who Ken Wexler was. He has definitely influenced my thinking more than he will probably ever know. I hope my future life as a research scientist will be of interest to him because then I will know, by definition, that I am doing interesting work.

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And thank you, Alan Prince, for being there to tell me to stand up and say just what I was saying, only louder. You are my savior.

I would also like to thank the faculty of the department in general for putting up with my ups and downs as a graduate student. The question is how there could have been so many downs with so seemingly few ups. I leave that as a mystery. And don't think that I didn't realize that you were probably cognizant of my downs. I thank you for not making me cognizant of your cognizance.

There are a number of people whose help was less tangible in every day life, but underlay my career as a graduate student. Jan Ellertsen made sure that I didn't have to worry about the administrative details of being a student and doing a thesis. Though it made my life easy, I'm sure it made her life not so easy. Steve Wadlow kept the computers running well enough that I didn't have to think about it. And he didn't delete my directory when I started using more disk space than everyone else. Pat Claffey always ordered the books that I asked for for the library. And Eleanor Bonsaint and Robin Nahmias were a real help with administrative matters local to building E10. Thank you all for making my life at MIT as easy as possible.

One thing that I am proud of after having been a graduate student at MIT for five years is the fact that I am as sane as I am.[1] Of course, my personal contribution to this feat was probably negative, so I must actually be proud of the people who balanced out

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[1]Cf. Poeppel (personal communication) for a different interpretation of the relevant phenomena.

that negative effect. These are many and varied. Here, I enumerate the most obvious, and then list other notables:

1. Paul Bloom. It was Paul's interest and enthusiasm that made decide to go to graduate school in cognitive science. And he may well have the best stories to tell about me. Ask him about Joe the UROP, and my discovery about children and psych verbs.

2. Sandeep Prasada. One might say that he was my student advisor when I entered the program. One might also say "no wonder things turned out the way they did," but I'm not sure what such a comment could possibly mean. With no one else have I shared the sitting and thinking about interesting problems, the class of possible approaches, and the most elegant solutions as often or as well. If, in practice, this isn't the most important part of a life in scientific research, then people must be practicing the wrong thing. Maybe they should be practicing their golf game. I look forward to sitting and thinking with him again in Philadelphia.

3. David Poeppel. One might say that I was one of his student advisors when he entered the program. But where Dr. Prasada's skepticism is grounded in optimism, my skepticism is grounded in cynicism. Fortunately, I finished my thesis and if anything is antithetical to the cynic's program, it's actually finishing a thesis. May this be my last lesson in why we are in the field: It is because the field is interesting, and by being in the field and thinking seriously about serious problems, we are bound to do interesting things. By the way, thank you for *Werther*, and I consider us <u>even</u> after I fainted during our discussion of the nature of time.

4. Gavin Huntley-Fenner. "With him, I shared two activities that truly took my mind off of my troubles: Brewing beer (with the illustrious Dr. Prasada) and playing the blues. Before I met him, I did neither; after I met him, I did both. Good or bad? You decide. I already have," he said, with degree nearly in hand.

5. Laura Klatt. Being able to talk to her about anything and everything has saved me from certain doom. At the same time, our discussions are an example of why I don't talk too much in general. I've talked to her more than I have to almost anyone, but that's probably just left her with false impressions rather than no impression at all. All in all, this might be better than worse, but there are two false impressions that I should like to dispel: I like your hair short and I like country music.

6. Amy Poeppel. Why can't any actress playing a character named

Dominique act? I know that Felicia is beautiful, but there's just *something* wrong with her. The new A.J. was in Karate Kid III! What happened to Tiffany?!? And...what's with Robert's hair? Maybe it's appropriate that they changed the theme song; it won't be the same without you....

7. Mary Ramsay. My oldest and dearest friend. May we never lose track of each other again. I suspect that we won't.

I would also like to thank Colleen Donovan, Laura Klatt and Katy O'Reilly, Sergey Avrutin, Suzie Johnson, and David and Amy Poeppel for saving me from the dungeon of E10, Annie Senghas for making morphology fun, John Houde for teaching me the theraputic value of hitting a small white ball with a big metal club, Renee Oatway for reassuring me that I can do cognitive science, Mike Scharf for waking my muse, Ezra Gould for teaching me the value of building things first and fixing things later, and, for their friendship, Marvin Chun, Marie Coppola, Daphne Bavelier, Kevin Brohier, Beth Fenner-Huntley, Zoubin Ghahramani, Anne Harris-Wilcox, Tony Harris, Michelle Hollander, Pauline Jacob, Robbie Jacobs, Arik Kapulkin, Gary Marcus, Adee Matan, Kelly Olguin, Neal Perlmutter, Flip Sabes, William Snyder, Gregg Solomon, Josh Stern, Claudia Uller, Michael Ullman, Jen Wolfe, and Fei Xu.

Finally, I would like to thank my family for their support during my life as a student. I take my sister, Arlene, as a symbol of inspiration: I wish I had turned out a little more like you. Maybe I still have a chance. As for my parents, well, I just can't say enough. So instead of trying and being hopelessly incomplete and incoherent, I won't say anything except *thank you*. Kimyong and Kisook, I dedicate this thesis to you.

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TABLE OF CONTENTS

CHAPTER 1

Why No Mere Mortal Has Ever Flown Out To Center Field[2]

[2]Kim, J. J., Pinker, S., Prince, A. S. & Prasada, S. (1991). Why No Mere Mortal Has Ever Flown Out to Center Field. *Cognitive Science*, **15**, 173-218.

Introduction

At the very heart of grammar are formal categories like *noun, verb,* and *adjective.* To most linguists it is virtually unthinkable that a theory of the psychology of language could do without mental representations of them: They define regularities in the syntax and morphology of virtually any sentence that a speaker utters. Yet, perhaps because of the very ubiquity of grammatical categories and the complexity of the linguistic structures they govern, clear and simple arguments for their psychological reality are not easy to find in the literature, and many philosophers, psychologists and computer scientists remain skeptical. In this paper we focus on a simple domain (one of many that could be chosen) in which it can be shown conclusively that grammatical categories and morphological structure play a subtle but powerful role in linguistic behavior. The domain has special relevance because it has recently figured in attempts to show that connectionist models (networks of densely interconnected simple neuronlike units) make traditional grammatical categories and structures obsolete.

In English, there are two types of verbs, those that have a regular suffixed past tense form, such as *walk/walked, jump/jumped,* and *open/opened,* and those belonging to one of several lexically restricted classes, which use other modes of past tense formation, such as *blow/blew, sing/sang, eat/ate,* and *break/broke.* A familiar simple account of the knowledge of the past tense of English verbs is that a regular rule generates the past tense form of regular past tense verbs, and irregular past tense forms are simply memorized by rote.

The familiar account fails, however, to capture the fact that irregular past tense verbs tend to pattern with other phonologically similar verbs (Bybee & Slobin, 1982; Bybee & Moder, 1983). Examples include the class where the stem has an *i* followed by a velar nasal consonant, such as *sing/sang, ring/rang, spring/sprang, drink/drank, shrink/shrank, stink/stank,* and the closely related class *string/strung, sting/stung, swing/swung, sling/slung, wring/wrung,* and so on. Within the rote-memory account, these similarities are purely incidental, a historical residue of the Old English strong verb classes.

However, clusters of irregular past tense verbs are not completely unproductive, which suggests that their phonological structure plays a role in the mental processes governing their use. Historical evidence for this semi-productivity is the fact that a

number of verbs, namely *catch/caught*, *cost/cost*, *fling/flung*, *kneel/knelt*, *quit/quit*, *sling/slung*, *stick/stuck*, and *string/strung* have been assimilated into irregular past tense clusters within the past several hundred years under the influence of similar existing clusters of irregular verbs (Jesperson, 1942/1961). Furthermore, many dialects of English show that the subregularities must have been at least somewhat productive at some time. For example, *thunk* is a common past tense form for *think*, which presumably is due to the partial productivity of the *sting/stung* cluster. Children, of course, occasionally use forms like *brang* for *brought*, *bote* for *bit*, and *truck* for *tricked*. Finally, Bybee and Moder (1983) showed that when experimental subjects are asked to produce the past tense form of a novel verb (e.g., *to spling*), the likelihood of an irregular past tense response (e.g., *splung*) increases with the phonological similarity of the novel verb to the phonological prototype of an irregular past tense cluster.

Rumelhart and McClelland's (1986) connectionist model of the acquisition of the past tense of English verbs was able to represent the similarity among irregular past tense clusters of verbs and to capture the semi-productivity of those clusters. The parallel distributed processing architecture of the model, in conjunction with the phonological representations that the model used, allowed it to find similarities among the instances of the irregular past tense verbs it was trained on, and to generalize to new forms based on their similarity to the forms in the training set. The model, often characterized as an alternative to symbol-processing or rule-based accounts of the acquisition and knowledge of language, made no reference to formal linguistic notions such as "verb root," "rule," and "lexical item."

In the model, a base form was represented by a pattern of activation within a vector of nodes each of which, when turned on, represented a phonological property that the stem possessed (e.g., stop consonant at the beginning, high vowel between two voiced segments). The network had an output vector with a similar structure, which represented the computed past tense form of the verb. Thus the model performed the stem-to-past mapping based solely on the basis of phonological information. Every input node was connected to every output node by a connection with a modifiable weight. Presented with a series of stem-past pairs, a learning mechanism strengthened connections between phonological properties of the stem and those of its past tense form. This allowed the network to reproduce the pairs in the training set and to generalize to new forms on the

basis of their phonological similarity to the pairs in the training set. The model treated regular and irregular past tense formation as a unified phenomenon, encoding them in a single network. The fact that regular past tense formation seems to have the status of a linguistic rule simply reflects the predominance of regular past tense verbs in English, which causes strong connections to be set up between many stem features and the features in the *-ed* set of endings.

According to Rumelhart and McClelland (1986), their model implies that children may not have mental representations of rules or lexical items. Moreover, they note that the basis for their model's successful performance is its sensitivity to details of the phonological representation of the stem:

> We have, we believe, provided a distinct alternative to the view that children learn the rules of English past-tense formation in any explicit sense. We have shown that a reasonable account of the acquisition of past tense can be provided without recourse to the notion of a "rule" as anything more than a *description* of the language. ... The child need not figure out what the rules are, nor even that there are rules. The child need not decide whether a verb is regular or irregular. There is no question as to whether the inflected form should be stored directly in the lexicon or derived from more general principles. There isn't even a question (as far as generating the past-tense form is concerned) as to whether a verb form is one encountered many times or one that is being generated for the first time. A uniform procedure is applied for producing the past-tense form in every case. *The base form is supplied as input to the past-tense network and the resulting pattern of activation is interpreted as a phonological representation of the past form of that verb. This is the procedure whether the verb is regular or irregular, familiar or novel.* (p. 266, emphasis added).

Indeed, the fact that weighted combinations of phonological features largely suffice to discriminate regular verbs from irregular verbs, and different kinds of irregular verbs from each other, is a surprising and interesting discovery of their modeling effort. In sum, the model's exclusive dependence on phonological information is the basis both for the more radical claims about the psychological unreality of formal linguistic constructs, and for its most interesting contributions to our understanding of morphological phenomena.

In this article, we will address neither Rumelhart and McClelland's (1986) model in general (see Lachter & Bever, 1988; Pinker & Prince, 1988; Prince & Pinker, 1988 for such detailed critiques), nor the issue of connectionism versus rule-based architectures.

We focus only on whether the input to linguistic mappings, in this case the mapping from English verb stems to their past tense forms, requires information about formal grammatical structure, including grammatical categories such as lexical item, form class, and past tense rule, or whether it can be represented solely in terms of phonological information. We show that past tense formation makes crucial use of formal constructs such as verb root, rule, and lexical item. We also show that a semantic alternative to the formal category account is empirically untenable. The demonstrations do not constitute evidence against connectionism, but they do constitute evidence against any model, connectionist or otherwise, that lacks representational devices dedicated to grammatical distinctions.

The Need For Formal Linguistic Representations

Though the semi-productivity of irregular past tense clusters may seem like justification for making phonological representations the sole determinant of the past tense form of a verb, this move has disastrous empirical consequences.

Lexical item as the locus of idiosyncrasy

Given the fact that some pairs of verbs have homophonous stem forms but different past tense forms, it is clear that phonological properties cannot be the sole determinant of the past tense form of a verb.

(1)	a.	Jimmie *rang* the bell.	ring/rang
		Jimmie *wrung* the washcloth dry.	wring/wrung
	b.	Preston *lay* on his bed.	lie/lay
		Preston *lied* to me again.	lie/lied
	c.	Kim *hung* a painting on the wall.	hang/hung
		The executioner *hanged* the criminal.	hang/hanged
	d.	That shirt never *fit* Fran.	fit/fit
		The tailor *fitted* Fran with a shirt.	fit/fitted

Somehow these homophonous verbs must be given nonidentical representations when they are input to whatever process derives the past tense form. The linguistic notion

of "distinct lexical entries" is the standard way of expressing this distinctness: The verbs in each pair of sentences are not represented as the *same item*; they have separate entries in the mental lexicon, each of which can have (or not have) an irregular past tense form linked to it.

Because the pairs in (1) need only be distinguished by some representational difference, one might think that lexical entries, conceived of as abstract indices or addresses, are not strictly necessary. In each case the different verbs have different meanings that must be represented somewhere. Because this difference in meaning has to be represented in any case, perhaps it could be used as part of the input to the past tense system, providing the representational difference that the system needs to distinguish homophonous verbs with different past tense forms. Adding a set of semantic features to the input vector is the obvious augmentation of the Rumelhart and McClelland model, and has been suggested by MacWhinney and Leinbach (1990). However, adding semantic features to a distributed representation has additional consequences. As Hinton, McClelland, and Rumelhart (1986) pointed out in their tutorial, "one of the most interesting properties of distributed representations [is that] they automatically give rise to generalizations" (p. 82). In fact, "any subset of the microfeatures can be considered to define a type. ... This allows an item to be an instance of many different types simultaneously." (p. 84). Thus the addition of semantic features would not only distinguish homophonous verbs, but at the same time would define semantic subtypes of verbs (those that share some of the distinguishing semantic features) that would be expected to show similar behavior in past tense formation, just as overlap in phonological features defines clusters of verbs with similar past tense forms.

But this consequence turns out to be false. The past tense form of a verb does not directly depend in any way on recurring semantic distinctions. For example, consider the verbs *slap, hit,* and *strike*. They are similar in meaning, but they have different past tense forms: *Slap* has the regular past tense form *slapped, hit* has the no-change irregular past tense form *hit*, and *strike* has the irregular past tense form *struck*. Thus, similarity of meaning does not imply similarity of form. Conversely, phonological clusters of irregular past tense verbs are not semantically cohesive: Similarity of form does not imply similarity of meaning, either. Consider the *sting/stung* class of irregular past tense verbs: *sting, sing, drink, shrink, swing, sling, spring, stink, ring*. There is no set of

semantic features that seems to distinguish these verbs from those that take different past tense forms, nor is there a set of semantic features that partitions this set of verbs into those that have a past tense form that changes the vowel to an *a* and those that change the vowel to an *u*. Semantic features would not help in learning these distinctions; they would just get in the way.

The independence of semantics and past tense form has other striking consequences: If several forms are sensed as being built out of the same verb morpheme, they will all have the same irregular past, no matter how semantically dissimilar. Verbs like *take, put, give, make, have, come, go*, and *set*, sometimes called "light verbs," have many meanings, especially when combined with prefixes such as *be-*, *for-*, *under-*, and *over-* and particles such as *up, out, in, off*, and *away*. However, they resist regular forms across all such incarnations, no matter how tenuous the semantic thread that might be said to hold them together (e.g., *took/*taked a walk, took a bath, undertook, took off, took in; came/*comed up, came around, became, overcame*).

None of this implies that it is impossible to use semantic information as a way of distinguishing homophonous verbs with different past tense forms. For example, one could add a set of units to the input bank upon which each verb that needed to be distinguished was given an orthogonal activation vector. Of course, in that case the units would simply be a code for the standard notion of "distinct lexical item"; in no sense would they be *semantic*. Alternatively, the system could somehow be constructed so that any difference in the semantic representation would be treated as indicative of a potential difference in morphology, and would feed into distinct bits of hardware representing unique phonological mappings for each of the combinations of values of the semantic features. But these distinct mappings, contingent on the mere *existence* of a semantic difference, independent of the actual patterns of semantic features across verbs, would also be implementations of the notion of pure distinctness of wordhood that is captured by the construct of lexical entries. As such, they run counter to the automatic construction of generalization-supporting subclasses that Hinton, et al. (1986) considered to be one of the virtues of connectionist models employing distributed representations.

Regular past tense formation as a rule

The regular past tense form is not just one of several kinds of annotations to a verb's entry; it has a special status as a *default* rule that applies automatically whenever it is not

explicitly blocked by a competing irregular. This asymmetry is shown by a phenomenon discussed by Mencken (1936), Kiparsky (1982a, 1982b, 1983), and Pinker and Prince (1988): Denominal verbs (those analyzed by speakers as having been derived from, or as being built around, a noun) have regular past tense forms, even if homophonous with, or ultimately derived from, an irregular verb. Examples are shown in (2); (a) and (b) are due to Paul Kiparsky; (c) - (j) are from Pinker and Prince (1988); (k) was provided by Lila Gleitman (personal communication, October, 1989).

(2) a. He *flied out* to center field.	*flew
b. He *grandstanded* to the crowd.	*grandstood
c. He *spitted* the pig.	*spat
d. He *braked* the car suddenly.	*broke
e. He *ringed* the city with artillery.	*rang
f. Martina *2-setted* Chris.	*2-set
g. He *sleighed* down the hill.	*slew
h. He *de-flea'd* his dog.	*de-fled
i. He *righted* the boat.	*rote
j. He *high-sticked* the goalie.	*high-stuck
k. The doctor *casted* his arm.	*cast
l. Vera *costed* the equipment requests in the grant proposal for us.	*cost
m. Chris Chelios of the Canadiens had *cheap-shotted* him. (*Boston Globe*, 4/26/90)	*cheap-shot
n. I *big-ringed* it the rest of the way. (i.e., used the big chain ring while bicycling; from a bicycle magazine).	*big-rang
o. In each of the past two seasons, Cleveland State guard William Stanley has sported a self-styled, one-of-a-kind hairdo. In 1987-88 it was a half-foot-high flattop. Last season he went to a bilevel box cut. This season, as a senior, Stanley has *outdo'ed* himself. (*Sports Illustrated*, 12/6/89)	*out-done

In all of these examples, the verbs, though homophonous with irregular past tense

verbs, are regular; all are transparently based on nouns or adjectives. Informally, one can account for this contingency by saying that irregularity is a property listed in the lexical entries of *roots* of words, not the words themselves. A verb derived from a noun has a noun root. Nouns cannot be listed in the mental lexicon as having an irregular past tense form because it makes no sense for a noun to have a past tense form at all. Therefore denominal verbs cannot be listed as irregular, and the regular rule applies by default. For example, the verb *to high-stick* is derived from the noun *stick*, which cannot have a past tense. Note that a change of category is a sufficient condition for regularization: It holds across noun and adjective roots, and across the heterogeneous semantic roles that the noun referent plays in the event denoted by the verb.[3]

However, this informal account is not precise enough to account for why verbs with a circuitous derivation from verb roots (e.g., V -> N -> V), such as *to fly out*, based on the noun *fly* (as in *pop fly*, *fly ball*), which in turn was derived from the verb root *to fly*, have a regular past tense: In some sense, they do have irregular roots.[4] A more precise version comes from Williams (1981):[5]

1. Derived words have a constituent structure (which can be shown as a tree structure), reflecting their derivation from more basic morphemes.

2. A constituent at any level of a tree inherits all the grammatical features of one of its subconstituents if and only if the subconstituent is in *head* position. In English, the head is ordinarily the rightmost constituent at a given level of decomposition.

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[3]Of course, a change of category is not a *necessary* condition for regularization; the examples in (1) show that distinct lexical regular and irregular entries for the same morpheme within the verb category are sometimes possible. As Dan Slobin points out to us, occasionally differences in register (formal versus informal), dialect (British versus American), or meaning can segregate one usage of a verb from another in a distinct lexical entry, which may then admit of a different past tense form, as in *She weaved/*wove through traffic* and *She knelt/?kneeled to pray; She ?knelt/kneeled to tie her shoe*; see the Appendix to Pinker & Prince (1988) for other examples, and Ullman and Pinker (1990) for discussion. Note that these examples are haphazard in terms of which verbs will split into different past tense forms and which of the two senses will be linked to the regular form. In contrast, the regularization-through-derivation effect is completely predictable, and, we will show, probably exceptionless.

[4]It also does not account for regularizations of certain complex nouns, as when *low-life* gets pluralized as *low-lifes*, not **low-lives* (cf. also *still lifes*, *hotfoots*, *walkmans*), even though such nouns have roots that are also nouns.

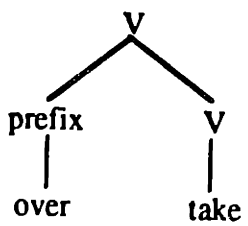
[5]For alternative accounts, see Kiparsky (1982a, 1982b, 1983) and Gordon (1986, 1989).

3. Irregularity is a feature of morphemes, like grammatical category, gender, and so on. Therefore a verb that is derived from a noun cannot have inherited all the features of its root, because if it had, the feature 'noun' would have been among them and it could not be a verb.

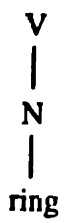
Therefore verbs derived from nouns cannot have heads; they are headless or *exocentric*. As a result, there is no way in such structures for features to pass up from a constituent morpheme to the whole. Therefore there is no way for the whole verb to inherit the 'irregular' feature from one of its parts, even if the part was marked as irregular. Therefore irregularity cannot be associated with denominal verbs and the past tense of such verbs are formed by the application of the default regular rule.

This can be illustrated by the examples in (3). The structure in (3a) corresponds to the verb *overtake* which has an irregular root, *take*, residing in head position, from which it passes on both the categorial feature 'verb' and the irregularity feature. In (3b), corresponding to *ringing the city*, shows how a verb derived from a noun is headless: The topmost node dominates a node of a different category, which would be impossible if that node were its head. Example (3c) shows that this is true even for circuitous derivations. The step in the derivation that derives the verb *(to fly out)* from the noun *(fly ball)* yields an exocentric structure, even though the noun itself was ultimately derived from the verb *to fly*. In fact, the step in the derivation that derives the noun *(fly ball)* from the root verb *(fly)* also yields an exocentric structure. Therefore, the derived verb has no head and, consequently, has no pathway for the irregularity of its root to percolate up to the top node representing the word as a whole.

(3) a.



b.



c.

An Alternative, Semantic Account

Lakoff (1987) suggested that models lacking representations for grammatical categories, connectionist models in particular, could handle past tense forms such as *flied out* if semantic information were encoded. His explanation is different, however, from the one discussed earlier in which the irregular/regular distinction would be contingent on sets of semantic features. He writes:

> [Pinker and Prince (1988)] cite the well-known fact that certain polysemous lexical items have different past tense forms for different senses of the verb. For example, *fly* in its central sense, takes the past tense *flew*, but takes *flied* in its extended baseball sense. ... There is a general constraint on such cases: It is always the central senses that have irregular past tenses.

Lakoff's proposal needs to be examined with some care; as formulated, it is too weak to be useful. The proposal offers only a one-way implication between centrality and irregularity: Given a polysemous verb which has irregularity *somewhere* among its cluster of senses, Lakoff predicted that the irregularity will necessarily infect the central senses. Nothing is predicted about the extended senses. "It is always the central senses that have irregular past tenses"; crucially, it is not the transparently incorrect 'always and only the central senses'. Lakoff's constraint permits a polysemous verb to have an irregular central sense and regular extended senses; or indeed to have any mixture of regular and irregular extended senses. What he ruled out is a polysemous verb with a regular central sense and irregular extended senses. In particular, Lakoff's constraint permits a polysemous verb to have an irregular past in *all* of its senses. But we are exactly trying to understand cases where the 'extended senses' must be regular.

Lakoff's constraint can be rephrased in this way: Regular central senses imply regular extended senses; or by contraposition, irregular extended senses imply irregular central senses. From this, it is clear that one is not licensed to draw any conclusions about the behavior of the extended senses when the central sense is irregular, or, even more pointedly, when the central sense belongs to a noun and is thus outside the verbal system of regularity/irregularity. Whether one accepts Lakoff's conception that *to fly out* is derived directly from *to fly* or whether we more plausibly relate it to the noun *fly (ball)*, there is no entailment from his constraint about the grammaticality of 'flied out' versus

'flew out'. The constraint must be strengthened if it is to have sufficient predictive power to compete with the grammatical theory. Yet one cannot go all the way to the biconditional "always and only," because, as noted above, hugely polysemous verbs can be irregular in all senses (e.g. *take, set, give*). No one wishes to claim that "only the central senses of a verb may be irregular." We therefore propose, as a worthy opponent to the grammatical theory, a gradient version of the semantic hypothesis:

(4) *The Semantic Centrality Hypothesis*: For an extended sense of an irregular verb, the tendency to regularize varies with the degree of sense-extension; the more extended the sense, the higher the probability that the verb will take regular inflection.

Under this hypothesis, the notion "extended sense" has some predictive capacity, even if only probabilistically; it can be investigated empirically. This theory can indeed provide an account for why all denominal verbs have a regular past tense, if denominal verbs are always construed as having complex, extended meanings based on the meaning of a noun. So it is possible to argue that both the formal grammatical theory and the semantic centrality theory make the same predictions with respect to denominal verbs, insofar as denominal verbs are extended in meaning.

It is worth noting that the semantic centrality theory is not obviously true in any absolute sense, even in the domain of simple nondenominal verbs. There are verbs that fit into the expected pattern of irregular-past-tense-forms/central-senses contrasting with regular-forms/extended senses, for example *to hang* and *to fit*, discussed earlier in (1). However, there do exist verbs that are irregular only in their extended senses, contrary to prediction. Consider these examples [(a) and (b) are from Pinker & Prince, 1988, p. 112]:

(5) a. He *wetted/*wet* the washcloth. The baby *wet/*wetted* his diapers.
b. They *heaved/*hove* the bottle overboard. They *hove/*heaved* to.
c. The baby *creeped/?crept* across the floor. The deadline *crept/?creeped* up on us.

There are, however, rather few clear examples of this type, and one could perhaps argue that the graded character of the semantic centrality theory allows even sporadic reversals of its main prediction. It is, therefore, important to distinguish the two accounts

with other evidence, and it is clear how to do it: The two theories make different predictions for deverbal verbs, that is, verbs with verb roots. The formal grammatical theory predicts that, given an irregular verb root, any two senses of that verb will both have the same irregular past tense form. The semantic centrality theory predicts that the extended senses are likely to have a regular past tense form, with likelihood increasing with degree of extension of meaning. For the semantic centrality theory, any difference between denominal and deverbal verbs per se is purely incidental.

The experiments reported herein have three purposes. First, we establish that the regularization-through-derivation effect is psychologically real. Though we think it is highly unlikely, a critic could maintain that existing regularized forms were created by historical processes no longer operating, or by the reasoning of editors, formal writers, and prescriptive grammarians, resulting in regular-irregular pairs that casual speakers simply reproduce by rote. Such a criticism might even be supported by the occasional counterexamples one hears, such as *He flew out* or *The Clippers fast-broke out of Buffalo.* But the suggestion can be refuted by showing that untutored subjects display the phenomenon in word forms they have never encountered before. Second, although existing pairs of homophonous words differing in past tense forms in English provide little support for the semantic centrality theory, they do not decisively refute it either. Consequently, we require a set of forms that independently vary according to the centrality of their meanings and their route of derivation. Third, we present evidence that certain apparent counterexamples to the grammatical category theory are, in fact, consistent with the theory, and caused by speakers' entertaining variant analyses of the items in question.

Experiment One

The word-level phonology hypothesis (embodied in the Rumelhart-McClelland model) predicts that all verbs that are homophonous with irregular past tense verbs will have an irregular past tense form: If only phonological information is input to the past-tense formation process, there is, *in principle,* no way to distinguish among phonologically identical verbs. The formal grammatical hypothesis predicts that only verbs with verbal roots in head position can have an irregular past tense form. All denominal verbs will

have a regular past tense form, even if they are ultimately related to some verbal root, whereas all deverbal verbs with irregular past tense roots will have an irregular past tense form. The semantic centrality theory predicts that central senses of irregular verbs will always have irregular past tense forms, but when they are used in an extended or metaphorical sense, they are likely to have a regular past tense form. The first experiment tested these predictions.

Method

Subjects. Thirty-two native English-speaking MIT undergraduates were paid for their participation in the experiment.

Materials. Thirty-seven verbs with irregular past tense or past participle forms were selected. (The principles discussed apply to participles as well as to preterites.) Each had a homophonous noun from which a denominal verb could be formed. Each verb also could be extended to form a deverbal verb, that is, an item with with an extended, noncentral meaning, but with the original verb as its head, suitable for testing the semantic centrality theory. Deverbal verbs were either metaphorical extensions of the original verb, or part of a novel compound. Thus, for each verb, a pair of items was constructed, one denominal, one deverbal. Each item had a context sentence that made the derivation of the verb clear: In the denominal contexts, the word was used as a noun (or as an adjective); in the deverbal contexts, it was used as a verb. Each context sentence was followed by two test sentences: One used the verb in a regular past tense, the other used the verb in an irregular past tense; they were otherwise identical. The verbs in the test sentences were underlined.

Eight of the 37 items used an existing denominal verb form and a metaphorical deverbal verb form (see 6a); these served mainly to demonstrate that the subjects respect the existing English distinctions previously discussed, counterexamples notwithstanding. The rest of the items used novel denominal forms. Eight of the remaining 29 items used a novel denominal verb form and a metaphorical deverbal verb form (see 6b). The final 21 items used novel denominal and deverbal compound forms (see 6c). Items of the forms (6a), (6b) and (6c) will be referred to as Subexperiments A, B and C, respectively. (See Appendix A for a list of the materials.)

(6) a. **Existing Denominal:**

Wade Boggs has a bad habit of hitting fly balls into center field.
In yesterday's game, he got one hit, and then flied out twice to center field.
In yesterday's game, he got one hit, and then flew out twice to center field.

Metaphorical Deverbal:

The math professor flies off the handle at the slightest things.
Last week, he flied off the handle when one student talked during class.
Last week, he flew off the handle when one student talked during class.

b. **Novel Denominal:**

When guests come, I hide the dirty dishes by putting them in boxes or
in the empty sink.
Bob and Margaret were early, so I quickly boxed the plates
and sinked the glasses.
Bob and Margaret were early, so I quickly boxed the plates
and sank the glasses.

Metaphorical Deverbal:

When guests come, if they arrive with slides my hopes for a lively
evening quickly sink.
When I saw Bob and Margaret carrying six boxes,
my hopes sinked instantly.
When I saw Bob and Margaret carrying six boxes,
my hopes sank instantly.

c. **Novel Denominal Compound:**

I've had so many light beers, I'm sick of them; I don't think I
could possibly drink another one.
As far as beers are concerned, I'm totally lighted-out.
As far as beers are concerned, I'm totally lit-out.

Novel Deverbal Compound:

The stewardess had been trying to light up her face with a smile

so much that day, she couldn't do it one more time.

As far as her smile was concerned, she was totally lighted-out.

As far as her smile was concerned, she was totally lit-out.

Design. There were two counterbalancing factors, defining four versions of the questionnaire. In each version a given verb appeared either in a denominal or a deverbal context, such that half the 37 items (plus or minus one) were denominal and half the items were deverbal. There were two complementary sets of items, such that if a given verb morpheme appeared in its denominal form in one set, it appeared in its deverbal form in the other set. The division into sets was done so that within a set, half the verbs from each of Subexperiments A, B, and C were denominal items and half were deverbal items. Each of the two sets in turn was presented in two versions: In one, the regular past tense form of a verb and its rating scale were presented above the irregular past tense form for half of the denominal items from each of Subexperiments A, B and C, and the irregular form was presented first for the other half; the same was true of the deverbal items. The other version had the complementary orders. Subjects were randomly given one of these four versions of the experiment such that an equal number of each of the versions of the questionnaire were distributed.

Twenty-two filler items with regular past tense verbs in a deverbal context were intermixed with the experimental items. These items were in the same format as the experimental items. For these filler items, subjects were presented either with the regular past tense form and a no-change form (e.g., *asked/ask*) or the regular form and a novel irregular past tense form phonologically similar to an existing irregular past tense form (e.g., *believed/beleft*). These were included to draw attention away from the independent variables (which, in fact, were invisible to all the subjects when queried), and to provide subjects with clear examples of good and bad regular and irregular forms, so that they would not feel compelled to exaggerate perceived small differences among the experimental items simply to distribute their ratings across the entire scale within the questionnaire.

Procedure. Each subject was asked to rate how natural sounding the regular and irregular past tense forms of a verb were in a given context on a scale from 1 to 7, where 1 meant *very unnatural sounding,* and 7 meant *very natural sounding.* The meaning of

the rating scale was explained with examples, none of which provided information about the derivation effect. First, an example was given in which the irregular past tense form was clearly natural sounding and the regular past tense form was clearly unnatural sounding: *He came/*comed home to Boston.* Subjects were then instructed that of the regular/irregular past tense sentence pairs for a given item, "just because one sentence sounds good, it doesn't necessarily mean that the other sounds bad or vice versa." This was illustrated by pointing out that many people find both *dreamed* and *dreamt* acceptable, and thus would give high ratings both to *She dreamed that she was falling out of a plane* and *She dreamt that she was falling out of a plane.* To encourage subjects to attend to the contexts of the sentences, they were told "to rate how the entire sentence sounds, not just the verb itself. In fact, a particular verb can sound good in one context and bad in another. ... So remember to read the sentences carefully so you understand their meanings perfectly well before making your judgment." To emphasize this point, the following example was given in which the context of a verb determines whether or not it takes a regular or irregular past tense form: *hanged/?hung the criminal; hung/*hanged the painting.* Note that this example does not exemplify the noun/verb contrast being studied. Subjects were also explicitly instructed that their judgments were to be based on their "own intuitions of colloquial speech, and not necessarily what is 'proper' or 'standard' or 'formal'." The following example was given in which the irregular past tense form is somewhat stilted, yet prescriptively deemed the *correct* form: "You might think that *slew* sounds weird or stilted [as the past tense form of *slay*] and *slayed* sounds a bit better, but that the 'proper' form is *slew* and thus you might be tempted to give *slew* a high rating. We ask you not to reason this way; just rate how natural the sentence sounds *to you.*" Finally, subjects were instructed not to give high ratings to forms "that would be used only 'jokingly' or in a kind of a word game. For example, the Legal Seafood restaurant is famous for serving a kind of fish called scrod. As a joke, they used to give away t-shirts that said 'I got scrod at Legal Seafood.' This is an example of word play; no one would really use the word *scrod* in their ordinary speech as the past tense of *screw* (unless they were making a joke). If you share this judgment, then you would give a low rating to that sentence."

Results

Irregular past tense forms were rated better than regular past tense forms for deverbal verbs, and regular past tense forms were rated better than irregular past tense forms for denominal verbs. The mean ratings are given in Table 1 and shown in Figure 1. A four-way Analysis of Variance (ANOVA) was performed on past tense ratings, with subjects as the random variable; the independent variables were item version, order version, verb root (denominal/deverbal), and past tense form (regular/irregular). As predicted by the grammatical category hypothesis, the interaction between the verb root and past tense form variables was highly significant, $F_{subjects}(1,30) = 517.60$, $p < .001$. A three-way ANOVA (Order Version x Verb Root x Past Tense Form) was performed on past tense ratings, with items as the random variable. The interaction between the verb root and past tense form variables was again highly significant, $F_{items}(1,36) = 155.80$, $p < .001$.

Insert Table 1 about here

Insert Figure 1 about here

Some of the items had differences in spelling or capitalization between the denominal and deverbal versions of a given verb. To show that the effect is not confined to morphemes that are marked as different lexical items by these orthographic devices, subject- and item-based analyses were performed with only the items for which there were no spelling or capitalization differences between denominal and deverbal forms. The mean ratings for these items are given in Table 1; the crucial interaction between verb root and past tense form was significant with both random variables: $F_{subjects}(1,30) = 407.42$, $p < .001$; $F_{items}(1,23) = 99.04$, $p < .001$.

The interaction between the verb root and past tense Form variables was significant

in separate four-way subject-based ANOVAs and in separate three-way item-based ANOVAs on past tense ratings for Subexperiment A, $F_{subjects}(1,30) = 750.54$, $p < .001$; $F_{items}(1,7) = 57.63$, $p < .001$; Subexperiment B, $F_{subjects}(1,30) = 323.07$, $p < .001$; $F_{items}(1,7) = 99.82$, $p < .001$; and Subexperiment C, $F_{subjects}(1,30) = 200.46$, $p < .001$; $F_{items}(1,20) = 109.92$, $p < .001$.

It is conceivable that while not all the irregular subclasses function as rules, some do. Mean ratings and results of separate two-way subject- and item-based ANOVAs (Verb Root x Past Tense Form) on past tense ratings for each of the phonological subclasses of the irregular past tense verbs (as defined in the Appendix of Pinker & Prince, 1988) are given in Table 2. In all the subject-based analyses, the interactions between verb root and past tense form variables were significant, and the interactions in the item-based analyses were significant in most cases.

Insert Table 2 about here

In fact, for *each of the 37 verbs*, the signed difference between regular and irregular past tense ratings for the denominal item is greater than that for the corresponding deverbal item. Furthermore, the irregular past tense form was rated better than the regular past tense form for each deverbal verb, and the regular past tense form was rated better than the irregular past tense form for 33 of the 37 denominal verbs. The four denominal verbs that had higher irregular past tense ratings than regular past tense ratings were: *broadcast, three-hit, out-blow, out-fling*. (See Appendix A for item means.)

The pattern of results for all analyses were similar to that shown in Figure 1, with the exception of the seven no-change irregular verbs: *hit, set, hurt, cast, shed, beat, split*. The mean regular rating (3.85) and the mean irregular rating (3.69) for the denominal items of no-change verbs are virtually identical, though the difference was in the direction predicted by the formal grammatical theory, and subjects' near-indifference still contrasted sharply with their strong preference for irregular forms for the corresponding verbs with verb roots. The interaction between the verb root and past tense form variables in a two-way ANOVA on past tense ratings is highly significant, $F_{subjects}(1,31) = 57.81$,

$p < .001$; $F_{items}(1,6) = 23.32$, $p < .01$. Although all no-change verbs in English end in a *t* or *d*, the indifference between regular and irregular past tense forms for denominals is not due to this phonological factor, but to something about the no-change verbs in particular. Verbs ending in *t* or *d* that were not no-changers in English did not elicit the same indifference, but behaved similarly to all the other verbs. This is shown by the relevant interactions in two ANOVAs with subjects as the random variable: When a factor is added contrasting no-change verbs with all the verbs that do not end in a *t* or a *d*, it takes part in a 2-way interaction with past tense form variable, $F_{subjects}(1,31) = 24.61$, $p < .001$, and in a 3-way interaction with past tense form and verb root variables, $F_{subjects}(1,31) = 70.90$, $p < .001$. However, when verbs ending in *t* or *d* that are not no-changers are contrasted with verbs that lack a *t* or a *d* ending, neither of these interactions is significant.

Discussion

The results of this experiment provide evidence against both the word-level phonology and the semantic centrality theories. The word-level phonology theory predicts that all the verbs used in the experiment, being homophonous with irregular past tense verbs, should have had higher ratings for irregular past tense forms than for regular past tense forms. The semantic centrality theory predicts that all the verbs used in non-central senses should have had higher ratings for regular past tense forms than for irregular past tense forms.

On the other hand, the results strongly confirm the predictions of the formal grammatical theory: Regular past tense forms are preferred to irregular past tense forms for denominal verbs, and irregular past tense forms are preferred to regular past tense forms for deverbal verbs. This was true for the data overall, with enormous levels of statistical significance both with subjects and items as random variables, for items not involving spelling or capitalization differences, for existing denominals with metaphorical deverbal counterparts, for novel denominals with metaphorical counterparts, for novel compound denominals with novel compound deverbal counterparts, and for each phonological subclass of irregular past tense verbs. In fact, the pattern of results predicted by the formal grammatical theory held for *each verb*.

Experiment Two

Many nonlinguists attribute conformity with grammatical principles to explicit training in composition and grammar in school. The regularization-through-derivation effect offers a very clear test of this assumption. Simple though the principle is, it appears that no one who has not studied modern generative grammar has been able to grasp it, let alone teach it, and this includes professional editors, prescriptive grammarians and other mavens, pundits, and language experts. For example, the following appeared in the ombudsman's column of the *Boston Globe* (Kierstead, 1989):

> A woman wrote: "I join other readers in lamenting the lack of attention given to good writing, spelling, and grammar these days." One article she sent left out a key comma and contained the phrase "he may of been." Another article read, "Martyny subletted a Kenmore square apartment." It's sublet. (p. 15)

Because for many people, the verb *to sublet* is more transparently derived from the common noun *a sublet* than the rare verb *to let* ("lease"), the offending headline is not surprising, and the ombudsman's implied apology is linguistically misguided.

H. L. Mencken, writing in *The American Language*, noted that

> the effort of purists to establish *broadcast* as the preterite has had some success on higher levels, but very little on lower. 'Ed Wynn *broadcasted* last night' is what one commonly hears. (p. 439, note 2.)

A modern example of what Mencken referred to can be seen in the style manual *The Careful Writer* by the late language columnist and *New York Times* editor Theodore Bernstein (1977):

> If you think you have correctly forecasted the immediate future of English and have casted your lot with the permissivists, you may be receptive to *broadcasted*, at least in radio usage, as are some dictionaries. The rest of us, however, will decide that no matter how desirable it may be to convert all irregular verbs into regular ones, this cannot be done by ukase, nor can it be accomplished overnight. We shall continue to use *broadcast* as the past tense and participle, feeling that there is no reason for *broadcasted* other than one of analogy or consistency or logic, which the permissivists themselves so often scorn. Nor is this position inconsistent with our position on *flied*,

> the baseball term, which has a real reason for being. The fact -- the inescapable fact -- is that there are some irregular verbs. (p. 81)

Bernstein's "real reason" for *flied* is the semantic centrality theory; he notes that it is restricted to a "specialized" field. Of course, Bernstein is bewildered by the popularity of *broadcasted* because the *real* real reason for *flied*, its derivation from a noun, can also lead to *broadcasted*, if that verb, too, is perceived as being derivable from a noun, in this case, as being 'to make a broadcast'.

Interestingly, Fowler (1965) correctly focuses on derivation, but incorrectly supposes that the relevant derivation was historical etymology, rather than psychological decomposition:

> If etymology is to be our guide, the question whether we are to say *forecast* or *forecasted* in the past tense and participle depends on whether we regard the verb or the noun as the original from which the other is formed. If the verb is original (= to guess beforehand) the past and p.p. will be *cast* as it is in that verb uncompounded; if the verb is derived (= to make a forecast) they will be *forecasted*, the ordinary inflexion of a verb. The verb is in fact recorded 150 years earlier than the noun, and we may therefore thankfully rid ourselves of the ugly *forecasted*; it may be hoped that we should do so even if history were against us, but this time it is kind. The same is true of *broadcast*; and *broadcasted*, though dubiously recognized in the OED Supp., may be allowed to die. (p. 206)

Surprisingly, *broadcast* itself was one of the few verbs in Experiment 1 for which the subjects were somewhat more consistent with the pleas of the prescriptivists than with the effects of a denominal derivation, though the derivation effect is still visible, as the regular form was rated 1 point better on the 7-point scale, and the irregular form 1 point worse, than in the metaphorical verb-root version. This interaction clearly derives from the same forces that were noted in the *Oxford English Dictionary* (OED; Murray, Bradley, Craigie & Onions, 1989) citation and the remark by Mencken, and that Fowler and Bernstein saw fit to condemn. The reasons why this particular item is one of the poorer instances of the effect in our data will be demonstrated in Experiments 4 and 5. For now it suffices to note that prescriptive language guides have spectacularly misunderstood the effect we are studying here, so they are unlikely to promulgate it via

formal education.

In this experiment we use our materials to assess the extent to which non-college-educated subjects might unconsciously be sensitive to a principle that is too subtle for the world's leading authorities on "correct" usage to discover.

Method

Subjects. Eight subjects responded to an advertisement in the *Boston Herald*, a tabloid. The ad solicited non-college-educated, native English-speaking persons over the age of 21 for the purpose of filling out a psychology questionnaire. Subjects were paid for their participation.

Materials, Design and Procedure. The questionnaires and instructions were the same as those used in Experiment 1.

Results

Irregular past tense forms were rated better than regular past tense forms for deverbal verbs, and regular past tense forms were rated better than irregular past tense forms for denominal verbs. The mean ratings are given in Table 3 and shown in Figure 2. A four-way ANOVA (Item Version X Order Version x Verb Root x Past Tense Form) was performed on past tense ratings with subjects as the random variable. The interaction between the verb root and past tense form variables was highly significant, $F_{subjects}(1,6) = 228.44$, $p < .001$. A three-way ANOVA (Order Version x Verb Root x Past Tense Form) was performed on past tense ratings with items as the random variable. The interaction between the verb root and past tense form variables was highly significant, $F_{items}(1,36) = 180.90$, $p < .001$. Both analyses were also significant when items involving a capitalization or spelling change were omitted: $F_{subjects}(1,6) = 134.65$, $p < .001$; $F_{items}(1,23) = 163.98$, $p < .001$.

Insert Table 3 about here

Insert Figure 2 about here

The interaction between the verb root and past tense form variables was significant in separate four-way subject-based ANOVAs and in separate three-way item-based ANOVAs on past tense ratings for Subexperiment A, $F_{subjects}(1,6) = 133.10$, $p < .001$, $F_{items}(1,7) = 55.69$, $p < .001$, Subexperiment B, $F_{subjects}(1,6) = 83.74$, $p < .001$, $F_{items}(1,7) = 72.08$, $p < .001$, and Subexperiment C, $F_{subjects}(1,6) = 119.03$, $p < .001$; $F_{items}(1,20) = 93.47$, $p < .001$.

Discussion

The results from this experiment replicate those from Experiment 1 and provide further support for the formal grammatical theory over both the word-level phonology and semantic centrality theories. This conflicts with the unfounded stereotype that uneducated people speak according to a simpler or more concrete grammar, and is to be expected given the fact, commonplace among linguists, that most prescriptive language instruction actually consists of minor features of a standard written dialect rather than the actual principles underlying speakers' knowledge of language.

Experiment Three

Although the results from Experiments 1 and 2 support the formal grammatical theory and provide evidence against the word-level phonological theory, there is an obvious escape hatch for the semantic centrality theory as long as there is no independent measure or criterion for determining what counts as "central" or "extended" in meaning. We have assumed that metaphoricity, compounding and denominalization all entail nearly equal degrees of extendedness. But one could argue that denominal verbs are on the whole *more extended* in meaning than metaphorical deverbal verbs. In the extreme case, if the denominal items from Experiments 1 and 2 were very extended and the deverbal items were, in fact, relatively central, then both the formal grammatical theory and the semantic centrality theory would be consistent with the results. Obviously, an independent measure

of centrality of meaning is needed to evaluate this possible counterexplanation.

In this experiment, we solicit subjects' ratings of the centrality of the sentences used in Experiments 1 and 2. Using this measure, we then test whether the data from Experiment 1 are explained equally well by the semantic centrality theory and by the formal grammatical theory. This can be done using a regression analysis: Given a predictor consisting of our independent measure of centrality of meaning, and a partially confounded binary predictor that codes whether a verb was derived from a verb or from a noun, the regression will tell us whether the centrality factor predicts a significant proportion of the variance of regularization strength among items when the confounded effects of grammatical category are mathematically held constant, and whether grammatical category has a significant effect when the confounded linear effects of centrality are held constant. For the semantic centrality theory to be correct, the significant effect in Experiment 1 must be predicted by semantic centrality, not by formal grammatical category, when their effects are disentangled across the full set of denominal and deverbal items.

A second prediction of the semantic alternative is that centrality should predict the goodness of irregular past tense forms of both denominal and deverbal verbs from Experiment 1, because any difference between denominal and deverbal verbs should be purely incidental. For reasons we discuss in full later, the grammatical category theory is consistent with some small effect of centrality but only if it is confined to denominals. (This is because the derivation might be "short-circuited" in some speakers for very central denominal senses, leading them to derive the verb directly from a related verb, for example, when *to sublet* is perceived as coming directly from *to let*, rather than via *a sublet*). However, no effect at all should obtain within the deverbal items.

Method

Subjects. Twenty-four native English-speaking MIT undergraduates were paid for their participation in the experiment.

Materials. The denominal sentence pairs and the deverbal sentence pairs from Experiment 1 were modified such that past tense forms of verbs were changed to nonpast forms where possible. This could not be done for certain sentences with adjectival passive participles such as the colloquial *I'm completely shaked-out/shaken-out.* For

these items, both regular and irregular participle forms were provided, so that subjects could choose and rate the form they preferred. For each verb, a third pair of sentences was constructed in which the verb was used in its concrete central sense; it was with respect to these sentences that we could assess the degree of semantic extendedness. An example of each of these items is given in (7):

(7) a. **Deverbal verb used in a central sense.**
Some metal things manage to stay afloat in Lake Erie, like tin cans.
It's a sure bet that rocks will sink when thrown into the lake.

b. **Deverbal verb used in a metaphorical sense.**
When guests come, if they arrive with slides, my hopes for a lively evening quickly sink.
When I see Bob and Margaret carrying boxes, my hopes sink instantly.

c. **Denominal verb.**
When guests come, I hide the dirty dishes by putting them in boxes or in the empty sink.
If Bob and Margaret come early, I'll quickly box the plates and sink the glasses.

Design. There were three versions of the experiment, each given to a random third of the subjects. Each version included either the denominal, the metaphorical deverbal, or the central verbal item for any given verb such that each version had the same number (plus or minus one) of denominal, metaphorical deverbal, and central-sense items.

Procedure. Subjects were told that they would see a verb in its stem form, followed by a pair of sentences. The pair of sentences would use that verb and make its intended meaning clear. They were then asked to rate how "central" or "extended" the meaning of the verb (underlined in the second sentence) is, based on "a gut feeling as to whether it is 'central' or 'extended'." The subjects were told that the rating scale ranged from 1 to 7, where 1 means *"is a central, basic meaning,"* and 7 means *"is an extended, distant meaning."* What was meant by "central" and "extended" was made clear by an example

using the word *to boot:*

> There is a relatively central sense: *The boy ran up to the dog and booted him* means that the boy kicked the dog. Then there is a slightly extended sense: *The bouncer booted the drunk out of the bar.* Here the bouncer may not have literally kicked the drunk; he merely removed him by force. A more extended sense can be seen in: *The boss was fed up with his assistant's incompetence and booted him out of the company.* Here no one even physically moved. A different kind of extension can be seen in: *The officer booted the illegally-parked car.* It means that the officer put a clamp called "the Denver boot" on the wheel of the car. Finally there is the expression: *I booted up my computer.* Here the extension is so distant that most people don't even know why the word is *boot* at all.

Subjects were also instructed to concentrate only on the meaning of the verb that is conveyed in the sentences, and not to spelling or capitalization:

> Sometimes a word will sound like another word but will not be related to it at all. For example, the word *walk* and the word *wok* (Chinese frying pan) are pronounced similarly, but neither is an extension of the other. We are not only talking about spelling. For example *a tire* (what's on a wheel) and *to tire* (to become fatigued) are unrelated even though they're spelled the same, whereas *Tastee-Freez* (a kind of ice cream) is related to *tasty* and *freeze* even though they're spelled differently. If a word seems totally unrelated to the target word, don't rate it at all; check off the box that says "unrelated." But if you sense any relation at all, even if it is a very weak one, please give us your rating.

For the items in which both regular and irregular past tense forms were presented, subjects were instructed to circle the form they preferred and to rate the centrality of that form. Items judged to be "unrelated" to the given verb stem were translated to a rating of 8.

Results and Discussion

A multiple regression was performed on the rating data for the 74 items (37 verbs, each in the denominal and deverbal versions) from Experiment 1. Specifically, the data to be accounted for consisted of the signed difference between the mean ratings of an item in its regular form and in its irregular form; deverbal and denominal versions constituted

separate items. Thus, we are seeing which variables predict the strength of the tendency to regularize. One predictor consisted of the mean centrality rating for each item. The other corresponded to the grammatical derivation of the item, and had a 1 for each row corresponding to a denominal item, and a 0 for each row corresponding to a deverbal item. The two predictors correlated 0.77, reflecting the fact that denominals were generally less central than deverbals. The regression analysis showed that the derivation of a verb uniquely accounts for a significant amount (22.8%) of the variance of regular minus irregular past tense ratings from Experiment 1, $F(1,71) = 53.80$, $p < .0001$. Centrality uniquely accounted for a very small (0.6%) and nonsignificant proportion, $F(1,71) = 1.28$, $p = .26$. An additional 46.6% of the variance was accounted for by the confounded effects of grammatical category and centrality.

Though the unconfounded predictive power of centrality was tiny, we wanted to see where it came from. Two simple regressions were performed on the signed difference between the mean ratings of the regular and irregular forms for each verb from Experiment 1. One regression included only denominal items; the other included only deverbal items. In each case centrality was the sole predictor. There was a small but measurable correlation between centrality and regular minus irregular ratings for denominal items, $r(35) = 0.25$, $p = .14$, but no correlation between centrality and regular minus irregular ratings for deverbal items, $r(35) = -0.01$, $p = .96$.

In sum, the semantic centrality theory is not supported by the results of the multiple regression: Grammatical category uniquely predicts a significant proportion of the variance in the degree to which a verb can have a regular past tense form (23%), and semantic centrality by itself predicts virtually none (1%). This shows that the results from Experiment 1 were, in fact, due to the grammatical category of a verb's root, and not to a confounded semantic factor. Furthermore, the semantic centrality theory is inconsistent with the fact that the 1% of the regularizability variance that is predicted by semantic centrality is confined to the denominal items. This result implicates some difference between the denominal items and the deverbal items independent of semantic centrality. In Experiments 4 and 5, we show that this asymmetry between denominal and deverbal items derives from factors that influence the path of the derivation of a verb.

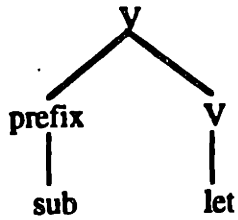
Experiment Four

The results from the previous experiments support the formal grammatical theory and disconfirm the word-level phonology and semantic centrality theories by the standards of psychology experiments, where unconfounded and statistically significant effects are deemed sufficient to establish the psychological reality of some factor. The grammatical category theory exceeds this criterion because *every* item in Experiment 1, not just a significant fraction, showed the predicted interaction. However, we will show that the theory can be pushed even farther: It can explain even apparent partial counterexamples like the four items that showed only an interaction, but not both simple main effects (i.e., whereas the signed difference between ratings for irregular and regular past tense forms was smaller for denominals than for deverbals, the difference for these items was not large enough to flip the preference and make the regular form *better* than the irregular form for denominal verbs.)

Recall from the quote from the *Boston Globe* ombudsman that both the regular (*subletted*) and irregular (*sublet*) past tense forms of the verb *to sublet* are acceptable to many speakers. The formal grammatical theory is consistent with this indifference *if* the two past tense forms are derived from different roots: A noun root for the regular past tense form, and an irregular verb root for the irregular past tense form. That is, if the verb *to sublet* is derived from the noun root *sublet,* it should have the exocentric, irregularity-blocking structure (8a), and its past tense form should be *subletted.* But if the verb *to sublet* is derived from the verb root *let,* it should have the properly headed, irregularity-passing form (8b), and thus, should maintain the irregular past tense form of its verb root. According to this proposal, people do not represent the category of the root as some fuzzy value intermediate between nounhood and verbhood, but are uncertain as to which of these two exact analyses is appropriate.

(8) a.

b.



As mentioned, one of the four denominal items with a higher rating for the irregular past tense form was the verb *to broadcast* (in the sentence *Last week, I think he broadcast/broadcasted the news every night*). This is predicted if the verb *to broadcast* has two possible derivations, one from an irregular verb root, and one from a noun root. This is not implausible, because, although the verb is easily thought of as derived from the noun *(news) broadcast*, it is also conceivably decomposed as a compound headed by the irregular verb *to cast*. In fact, according to the *OED*, the verb *to broadcast (the news)* was originally taken from the verb *to broadcast (seeds)*, meaning "to scatter seeds abroad with the hand," and even for nongardeners there may be enough transparency of the composition to support the perception among some that *broadcast* is headed by the verb root *cast*. If this could be demonstrated, the reduced effect of derivation for this verb, resulting in an unexpectedly acceptable irregular past tense form, would not be problematic for the formal grammatical theory, since denominalization is no longer

implicated.[6,7] (Of course, another possibility, suggested by the quotations from style manuals, is that the weakness of the effect is due to misguided prescriptivist efforts.)

There are other cases in which one might find that denominalization could be bypassed or short-circuited by an alternative derivation from a verb root. One plausible cause might be semantic similarity between a verb root and the denominal verb ultimately derived from it. For instance, though the verb *to fly out* is usually construed as being derived from the compound noun *fly ball*, it is also clearly related in meaning to the verb root *fly* and is even applicable if the ball is personified as its agent. This is occasionally seen elsewhere in sports descriptions, as in *Kareem got blocked* or *Kevin is rejected*; the verbs literally refer to the ball, not the person.

Such explanations of course must be supported by some independent measure of likelihood of shortcircuiting. There is mild support from Experiment 3, where centrality judgments for denominal items did account for a small but measurable amount of variance in the regularization strength among denominal items from Experiment 1, while, crucially, accounting for none of the variance in the deverbal items. It is plausible that the centrality of the meaning of the denominal form with respect to that of the original verb is a surrogate for whatever factors lead a person to perceive a supposedly denominal verb as derived directly from the original verb. If so, some effect of centrality is to be expected, opposite in direction to the overall effect of grammatical category. However centrality has no way of affecting deverbals. In this experiment we test for the possibility of a short-circuiting effect more directly.

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[6]Related examples are certain marginal forms we have noted in speech and writing such as *fair-caught* (= to make a "fair catch" in football; called to our attention by Lila Gleitman), *fast-broke* (= to make a "fast break" in basketball), *gunfought* (= to have a gunfight, provided by Paul Bloom), and *test-drove* (= to take a test drive). Presumably they are irregular because in each case the word could be reanalyzed as similar to an adverbial-verb compound with the verb as the head, as in the attested nondenominal *When I student-taught* (i.e., in an internship, while still a 'student teacher'). Indeed in each case the verb serving as the second member of the compound could have been used grammatically by itself within the sentence context (e.g., *I test-drove/drove the new car*; *He fair-caught/caught the football*).

[7]One unique case is *the workers struck*, meaning 'went on strike'. According to the *Oxford English Dictionary*, the verb came from the expression *to strike the machinery* (i.e., shut it down), the action that symbolically began the work stoppage. This sense of the verb survives today in *striking the sails* and *striking the set* (in drama productions). Thus the original coining of the word in its labor context respected the grammatical category theory, as it was an irregular verb derived from an existing irregular verb. This irregular form survives by some combination of prescriptiveness, surviving parallel forms, and metaphoricity. Interestingly, many people report *struck* as a learned, not quite natural-sounding form. This ambivalence is no doubt caused by the fact that the motivation for the original derivation is no longer very transparent and the deverbal noun *a strike* has become more basic.

Method

Subjects. Twelve native English-speaking MIT graduate students were volunteers in this experiment.

Materials. The context sentences of the denominal items were taken from Experiment 1. Because the meanings of many of the denominal verbs from Experiment 1 were opaque outside of the context of the initial sentence, the nouns themselves were taken for use in the rating task.[8] Sentences were constructed with a central use of the corresponding verb. The deverbal sentences from Experiment 1 were not used because they had been constructed to exemplify a highly noncentral sense, and if there is an effect of meaning, it should relate the nominal reading to the central sense of the verb root. An example is in (9):

(9) When it starts to get cold up north, most birds fly south for the winter.
Wade Boggs has a bad habit of hitting fly balls into center field.

Procedure. Subjects were presented with pairs of sentences like (9) and were asked to rate the similarity of the underlined words within the context of the respective sentences on a 7 point scale, where 1 means *very dissimilar in meaning* and 7 means *very similar in meaning*. They were instructed to ignore differences in spelling, capitalization, or syntactic category when making their judgments.

Results and Discussion

There was a significant negative correlation between similarity judgments in this experiment and the tendency to regularize denominal items in Experiment 1, measured as the mean rating of the regular form of the verb minus the mean rating of the irregular form, $r(35) = -0.54$; $p < .001$. That is, the more similar in meaning the two forms were judged to be, the smaller the difference between regular and irregular past tense scores for denominal items in Experiment 1.

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[8]We assume that the denominal verbs were similar in meaning to the nominal form from which they were derived, and that in this task similarity is transitive.

Furthermore, we predict particularly high similarity ratings for the four denominal items in Experiment 1 for which the derivation effect was not strong enough to raise the regular ratings above the irregular ratings. The mean similarity rating across all items was 2.30, and the similarity ratings of the four items in question were each above this mean (*three-hit*: 4.33; *out-fling*: 3.25; *broadcast*: 3.00; *out-blow*: 2.75). In a two-tailed, within-subjects *t*-test with subjects as the random variable, the mean similarity rating for these four items was significantly higher than the mean similarity rating of the rest of the items, $t(22) = 3.26, p < .005$.

These results support the short-circuit hypothesis by showing that the similarity in meaning between a denominal verb and a verb with a deverbal root predicts to a significant degree when denominalization can be bypassed in the derivation of a verb. This provides further support for the formal grammatical theory by showing that even for the minority of items in which the derivation effect acts more weakly, there is an independently supported explanation for why the effect is diluted.

It is important to note that the short-circuit theory, unlike the semantic centrality theory, is embedded as a special case within a theory of formal grammatical categories. That is, the short-circuit theory predicts when the effect of denominalization, a purely formal notion, might occasionally be bypassed. It contrasts sharply with the semantic centrality theory, which makes no reference to formal operations over linguistic categories such as denominalization, and hence, cannot explain the huge unconfounded effect of grammatical category, or the strict confinement of the small semantic effect to the denominal verbs.

Experiment Five

In Experiments 1 and 2 we showed that the mapping between particular English stems and their irregular past forms is bypassed when the stem is perceived to have been derived through a nonverb category. In an unpublished paper, Carlson, Keyser and Roeper (1977), using invented verbs like *dring*, showed that the more general process of mapping a stem *sound pattern* to its corresponding irregular past form is blocked under the same conditions.[9] (The fact that high phonological similarity, as well as strict

[9]We thank Tom Roeper and Greg Carlson for informing us of the study and for providing us with a copy of the paper, data, materials and instructions.

homophony, is overridden by derivation can be seen in existing English forms like *kinged/*kung the checkers piece, prided/*prode himself on his looks*, and *the engine pinged/*pung*.)

Their study also showed that the mere fact that a verb stem can exist as a noun is not the crucial factor; it is whether the verb in question is perceived as having been derived from the noun. This is exactly the claim behind the short-circuit hypothesis for why the derivation effect is sometimes diminished for certain words: A denominal verb is not perceived as being derived from the corresponding noun. It is also the obvious explanation for why, in English, irregular verbs can coexist with related nouns, as in *buy the car/this car is a good buy* or *read the book/this book is an easy read.* In such cases the verb is perceived as basic, and the noun as having been derived from it. Intuitions of which member of a noun/verb pair is basic presumably involve the semantics of the noun/verb distinction, such as the distinction between entities on the one hand and events or states on the other. For example, *an easy read* can plausibly be thought of as meaning *something that is easy for people to read*, but *to read the book* cannot easily be thought of as having been derived from the noun *read.* Conversely, in noun/verb pairs that involve an instrument (e.g., *high-sticked the goalie*) the noun is typically more basic.[10] Frequency of use as a noun versus a verb may also be correlated with which appears more basic. Note that the fact that semantics and frequency can correlate with regularization does not support the semantic centrality theory or compromise the grammatical category theory, because it is only those factors that independently go into distinguishing nouns from verbs in the language that play a causal role, and no factor specific to the past tense mapping itself.

Carlson, et al. (1977) presented subjects with novel verbs whose phonological form suggested that they might have irregular past tense forms by analogy to clusters of existing irregular past tense verbs. These novel forms were presented in contexts that

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[10]Though there are cases where the derivation may be ambiguous. Kiparsky (1983) explains the counterexample *string/strung/*stringed* by providing evidence that the verb is not derived from the noun *string* but instead is a manifestation of an abstract meaning that jointly underlies the noun and the verb. He points out that the clear cases of derivation from an instrument noun pertain to actions involving the narrow class of objects specified by the instrument noun (e.g., **She taped the picture to the wall with pushpins.*). But not all noun-verb pairs manifest this specificity and hence transparent directionality; e.g., *He brushed his coat with his hand. String* belongs to this latter class; its referent action does not require string at all: *He strung the tree with Christmas lights; String him up with a rope!; Tarzan strung his bow with a vine.*

suggested different derivations of the verb. In particular, a novel word was presented in the first of a pair of sentences as either a basic verb (see (10a)), a basic noun (see (10b)), or a deverbal noun (see (10c)). All but one of the deverbal noun contexts were "light verb" constructions as in (10c), which suggests that the novel noun had been derived from a verb, by analogy to such English constructions as *have a look/drink/try, take a walk/hike/break*, and so on. The other expressed a sound, analogous to *I heard three beeps*. In the second sentence of each pair, subjects were asked to fill a blank space with the appropriate form of the novel word in the initial sentence. The context required a past tense form of a verb.

(10) a. **Novel word used initially as a verb:**
It is astounding the way cats can *plive*.
Just the other day, I saw one that backed up and _____
right past me at full speed.

b. **Novel word used initially as a basic nominal:**
Last week, I borrowed my neighbor's *plive*.
I went and _____ several hard pieces of wood with it.

c. **Novel word used initially as a potentially deverbal noun:**
Last night, Max had himself a nice, long *plive*.
He _____ until well past midnight.

Assuming that subjects would store the novel words as exemplars of the grammatical category suggested in the context sentence, Carlson, et al. predicted that subjects would write in more irregular pasts when the stem was initially presented as a basic verb than as a basic noun, for reasons similar to those laid out here. However, the possibility of nounhood itself would not be sufficient to trigger regularization if it was apparent to subjects that the noun itself had been derived from a verb, and that the verb to be inflected was in fact that original verb, not a new one derived from the noun.

Approximately 120 subjects were each presented with eight basic verb contexts, four basic noun contexts, and four deverbal noun contexts. Sixteen novel words with sound patterns similar to English irregular verbs were presented, counterbalanced in

order and assignment to conditions. As Table 4 shows, a higher percentage of irregular forms were written in for verbs presented initially as verbs (19.3%) than verbs presented initially as basic nouns (10.2%). For verbs presented initially as nouns, which looked like derivations of the verb to be rated, irregular forms were written in at a rate slightly lower than that for verbs presented initially as verbs (16.0%), but still higher than that for verbs presented initially as basic nouns.[11] There was variation in the size of this difference depending on the verb, presumably because some irregular patterns are more easily generalized than others (e.g., compare *sping/spang* to *?treave/treft*), but over all items, the frequency of irregular past forms for basic noun contexts was less than that for basic verb contexts and less than that for deverbal noun contexts. This is exactly as predicted.

Insert Table 4 about here

Unfortunately, Carlson et al. did not perform inferential statistics, and the raw data are no longer available. Because their findings complement ours in showing the derivation effect with semiproductive sound patterns rather than existing English verbs, and in showing that the mere existence of a nominal form is not sufficient for the derivation effect (as required by the short-circuit hypothesis), it is useful to attempt to replicate it using methods similar to those employed in Experiment 1.

Method

Subjects. Forty native English-speaking MIT undergraduates were paid for their participation.

Materials. Thirty-two verbs similar in sound to existing English irregular verbs were used (see Appendix B). Sixteen were those used by Carlson, et al.; because the irregular past tense forms of some of them were not easily predictable given the stem

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[11] All percentages are based on the assumption that there were in fact 120 subjects; Carlson, et al. only reported the total number of irregular past tense responses for each verb, pooled across subjects.

form, we had 10 MIT students give the possible irregular past tense forms for those verbs and rank them from best to worst. We used the irregular form ranked highest most often. An additional 16 novel verbs were created; irregular past tense forms were selected on the basis of the English verbs they rhymed with.

Thirty-two sentence pairs were constructed. The initial sentence in 16 of these pairs used a novel word as a basic verb. The initial sentence in the other 16 of these pairs used a novel word as a noun. Of these 16, 8 used the novel word as a basic noun, and the other 8 used it in a form suggesting it was derived from a verb. This was encouraged by using the noun as the object of a light verb and by using durational adjectives, as in the sentences in (11).

(11) a. John had a nice, long drink.
b. John took a quick look.
c. John gave the dog a swift kick.

Each context sentence was followed by a pair of sentences using the novel word in the regular past tense, and in an irregular past tense; they were otherwise identical. In the three respective conditions, the sentence made it clear that the verb was either identical to the context verb, derived from the context noun, or identical to the verb from which the context noun had been derived. An example of each of these items is in (12):

(12) a. **Novel word used initially as a verb:**
Jeremy's mother warned him not to kleed.
When he disobeyed and kled anyway, he was told
he couldn't watch cartoons.
When he disobeyed and kleeded anyway, he was told
he couldn't watch cartoons.

b. **Novel word used initially as a basic noun:**
Mary got a brand new kleed for her birthday.
She liked it so much, she kled for a week.
She liked it so much, she kleeded for a week.

c. **Novel word used initially as a deverbal noun:**

It has been a long time since I have had a nice, long kleed.

I kled quite often in the old days.

I kleeded quite often in the old days.

Design. The sentences and novel verbs were paired in four random orders, with the constraint that a particular novel verb was paired with a basic noun context, a deverbal noun context, and two different basic verb contexts. For each order, a particular item had its regular past tense form presented before its irregular past tense form half the time. Subjects were randomly given one of the eight versions of the experiment such that an equal number of each of the versions of the questionnaire were distributed.

Procedure. Subjects were told that they would be rating the naturalness of sentences containing certain past tense forms of novel words on a 7-point scale, where 1 means *very unnatural sounding*, and 7 means *very natural sounding*. Subjects were instructed: (a) to read the first and second sentences carefully, and then to rate how good the past tense form of the novel verb in the second sentence sounded in the context of the two sentences, and (b) to read the first and third sentences carefully, and then to rate how good the past tense form of the novel verb in the third sentence sounded in the context of the two sentences. Subjects saw the examples from the instructions of Experiment 1 that emphasized that their ratings for the regular and irregular past tense forms of a given verb should be independent, and that they should attend to the context sentences.

Results and Discussion

As in the Carlson, et al. study, different stems elicited widely varying degrees of acceptance of irregular forms (e.g., subjects gave moderately high ratings to *spling/splung* but not to *nake/nook*). This raises the danger of a floor effect: Low ratings for irregular past tense forms across the board may obscure any difference between stems presented initially as a noun and those presented initially as a verb. Thus, analyses were performed only on those stems whose mean rating for the irregular past tense form, averaging over the three conditions, was higher than 4, the exact midpoint of the 7-point rating scale. This criterion, based on all and only the irregular past tense ratings for each novel stem, is independent of the predictions of the formal grammatical theory.

Using this criterion, 10 of the 32 stems were eliminated: *clare/clore, lang/lung, nake/nook, plare/plore, prall/prell, skrib/skrobe, snike/snoke, spiff/spuff, sprink/sprunk,* and *spoog/spug*. The mean ratings of regular and irregular past tense forms of the remaining items for the three contexts types are given in Table 5.

Insert Table 5 about here

In the first comparison we omit the deverbal noun items, since such contexts were not part of the design of Experiment 1. Separate two-way ANOVAs, one using subjects and the other using items as the random variable, were performed on past tense ratings, with verb root (basic noun/basic verb) and past tense form (regular/irregular) as independent variables. The interaction between verb root and past tense form variables was significant in both the subject-based analysis, $F_{subjects}(1,39) = 8.24, p < .01$, and the item-based analysis, $F_{items}(1,21) = 5.78, p < .05$.

The second comparison, relevant to the short-circuit effect, includes only items presented initially as nouns, and contrasts contexts presenting basic nouns with contexts presenting deverbal nouns. The interaction between the noun type (basic/deverbal) and past tense form variables was significant in the subject-based analysis, $F_{subjects}(1,39) = 4.34, p < .05$, and marginally significant in the item-based analysis, $F_{items}(1,21) = 4.17, p = .054$. As in the Carlson, et al. study, when subjects were presented with nouns in contexts suggesting that they were derived from verbs, they treated the verbs to be rated much like they treated verbs that had only been presented in clear verb contexts.

Thus both of Carlson et al.'s results are replicated: Subjects are less likely to extend an irregular mapping to a nonce verb perceived as having been derived from a basic noun than to a nonce verb perceived as having a verb root. And, it is not the presentation of the noun itself that is crucial, but whether or not it is perceived as the source of the verb whose past tense form is being considered. This difference is essential to the short-circuiting process that we suggest is responsible for the occasional dilution of the derivation effect.

General Discussion

Experiments 1 and 2 showed that subjects, including non-college-educated subjects, tacitly know that phonological and semantic information are not sufficient to determine the past tense form of a verb; rather, the grammatical category of the root of the item is the crucial factor. Experiment 3 showed that this is not due to a confound between derivation from a nonverb category and extendedness of meaning. These effects are pervasive in everyday speech, and in the experiments are highly robust and visible qualitatively in 89% of the items, and quantitatively in 100% of them. Moreover, even the dilution of the effect in some experimental items and the occasional apparent counterexamples in everyday speech can be explained within the grammatical theory, because its necessary and sufficient condition for the regularization effect -- that a verb be *perceived*, perhaps unconsciously, as having a noun root, not merely that such a noun exists -- may not always be met. The results from Experiments 3, 4, and 5 provide independent support for this explanation. Experiment 5 also provided a replication of Experiments 1 and 2 using novel verbs, thus showing that the effect holds both for extensions of existing words to new senses and for generalizations involving entirely new words.

These experiments clearly show that any theory that tries to account for native speakers' knowledge of the past tense of English verbs has to acknowledge that past tense formation depends on more than phonological and semantic information, but also makes crucial reference to abstract morphological structure, reflecting the path of derivation of the item, and to formal linguistic categories. Though the experiments speak against theories such as that of Rumelhart and McClelland (1986), we are not suggesting that they refute connectionist models in general, though they do put limits on the extent to which connectionist models (or any models) will weaken or revise theories invoking grammatical rules and structures.

Among the theories that would have difficulty with the present results are those that dispense with rules and rely on "analogy" to stored regularly inflected forms to explain the production of novel regular forms (e.g., Bybee, 1988; Stemberger, 1989). While one might get away with suggesting that people inflect *rick* as *ricked* by analogy with *pick/picked*, *nick/nicked*, and so on, the hypothesis runs into difficulty in accounting for the current results. First, we have shown that even the more plausible analogy-driven

extension of *irregular* patterns (e.g., *dring/drang*) is overruled when the grammatical analysis of the item suggests a nonverb derivation. Second, the computation of regulars in such cases cannot easily be driven by close similarity to stored regulars, because the similarity to irregulars is far higher and in many cases there are few or no relevant stored regulars to serve as an attractor. For example, there are very few nondenominal monosyllabic verbs whose pasts end in *-inged, -inked, -itted, -etted, -edded*, and *-eeted* (possibly none for *-inged* and *-itted*). Nonetheless, when the irregular was sealed off by denominalization, subjects gave high ratings to regular past tense forms for verbs similar to these sound patterns. It is hard to see how any analogy-driven model could handle the phenomenon unless properties of morphological structure were allowed to gate the analogy process.

These studies have important implications for language acquisition. Since formal grammatical representations, such as lexical category and abstract morphological structure, play a decisive role in determining whether a verb has a regular or irregular past tense form, children must come to represent such structures if they are ever to attain adult competence. In particular, in order to be able to acquire the fact that denominal verbs have regular past tense forms, children have to (a) know that irregularity is a property of roots, not of words; (b) decompose words into abstract morphological structures, so that the irregularity of roots can be passed up to the word through head positions; (c) represent the differences among grammatical categories; and (d) treat regular past tense inflection as having a default status so that it applies whenever it is not specifically blocked by irregularity.

It is not easy to show how children could learn these principles, and there is some evidence that they don't. Gordon (1986, 1989) showed that children distinguish between regular and irregular plurals in a qualitative way. As Kiparsky (1982a, 1982b) notes, most kinds of compounds can contain irregular plurals (e.g., *teethmarks*) but not regular plurals (e.g., **clawsmarks*) in compound-initial position. The explanation, which is related to the regularization effect studied here, is that irregular plurals are properties of noun roots listed in the lexicon and can go into the rule that combines roots to form compounds, but regular pluralization is a default operation that applies after all other morphological processes are complete and so does not have access to the internal constituents of noun-noun compounds. Gordon found that when 3-5-year-olds are asked

what to call a creature who eats "mice," they will often say "a mice-eater," but when asked what to call a creature who eats "rats," they virtually never say "a rats-eater," only "a rat-eater," in perfect accord with the adult principle. Gordon points out that these results are especially striking because the frequency of compounds containing plurals in compound-initial (i.e., non-head) position is vanishingly rare in English according to standard frequency counts. If children did hear plural forms in compound-initial position, they could notice that all of them contained irregulars, and none contained regulars, and conceivably could have learned the principle. The fact that the crucial input information is absent led Gordon to suggest that the basic organization of the morphological system, which distinguishes regulars and irregulars, is innate.

Many linguists have claimed that their investigations show that the psychology of human language involves some degree of inherent structure dedicated to grammatical representations and processes. At the same time, critics have charged that such constructs are not empirically testable, weak in their effects, confined to educated speakers, products of formal instruction, confounded with semantics, embarrassed by unexplained counterexamples, and learnable from input regularities. Perhaps some of this controversy stems from an unwillingness to accept the methodology of linguistics, with its reliance on judgments of grammaticality and meaning. Using a simple phenomenon and methods more familiar to psychologists, we have shown a case in which all of these skeptical suspicions about the psychological reality of basic linguistic constructs are unfounded.

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APPENDIX A. STIMULI AND ITEM MEANS FROM EXPERIMENT ONE

A.1 Existing Denominal vs. Metaphorical Deverbal

(The first item in each pair is denominal; the second is deverbal.)

1.	Wade Boggs has a bad habit of hitting fly balls into center field.	
	In yesterday's game he got one hit, and then flied out twice to center field.	4.2500
	In yesterday's game he got one hit, and then flew out twice to center field.	3.9375
	The math professor often flies off the handle at the slightest things.	
	Last week, he flied off the handle when one student talked during class.	1.8125
	Last week, he flew off the handle when one student talked during class.	6.8750
2.	The quarterback had a bad habit of trying to impress the crowd in the grandstand rather than concentrating on the game.	
	He grandstanded to the crowd once too often and got sacked.	4.5000
	He grandstood to the crowd once too often and got sacked.	1.8125
	Reagan was able to withstand the criticism directed against him by his political opponents.	
	Reagan easily withstanded the criticism.	1.7500
	Reagan easily withstood the criticism.	6.7500
3.	Dan Rather usually does the broadcasts for CBS on weekdays.	
	Last week I think he broadcasted the news every night.	3.9375
	Last week I think he broadcast the news every night.	6.0625
	The witch was always casting spells on people.	
	Last week I think she casted a spell on my uncle.	3.0625

	Last week I think she cast a spell on my uncle.	6.9375
4.	Brian needed nerves of steel to face the ordeal.	
	Brian steeled himself for the ordeal.	5.4375
	Brian stole himself for the ordeal.	1.3750
	Benzinger was good at stealing bases.	
	Last night, Benzinger stealed second base twice.	1.6250
	Last night, Benzinger stole second base twice.	6.9375
5.	Sam always tells lies when he wants people to think he's better than he really is.	
	He lied to me again last night about how good a golfer he is.	7.0000
	He lay to me again last night about how good a golfer he is.	1.0000
	The cure for cancer currently lies out of reach because scientists don't know enough about how the body works.	
	The smallpox vaccine once lied out of scientists' reach too.	2.1250
	The smallpox vaccine once lay out of scientists' reach too.	5.6250
6.	General Patton ordered his artillery to form a ring around the city.	
	He quickly ringed the city with artillery.	5.0625
	He quickly rang the city with artillery.	2.6250
	Songs of freedom were ringing through the land.	
	Songs of freedom ringed through the land.	1.7500
	Songs of freedom rang through the land.	6.9375
7.	The truck driver applied the brakes suddenly to avoid an accident.	
	He braked the truck suddenly.	5.8750
	He broke the truck suddenly.	1.1875

The plant superintendant has the job of breaking in new employees.

He breaked in half a dozen people this week.	1.5625
He broke in half a dozen people this week.	6.5000

8. After she was finished repairing the boat, she set it upright.

She righted the boat after she fixed it.	5.8125
She rote the boat after she fixed it.	1.3750

After the crash, she had to write off her losses on the car.

It was the third time this year that she writed off a loss.	1.0625
It was the third time this year that she wrote off a loss.	6.8125

A.2 Novel Denominal vs. Metaphorical Deverbal

(The first item in each pair is denominal; the second is deverbal.)

---

1. He always puts the pig on a spit to roast it over a fire.

Again last night, he spitted the pig.	3.7500
Again last night, he spat the pig.	2.5000

Whenever I come up with a suggestion, he always spits on it.

Again last night, he spitted on my idea.	2.2500
Again last night, he spat on my idea.	5.8125

2. When guests come, I hide the dirty dishes by putting them in boxes or in the empty sink.

Bob and Margaret were early so I quickly boxed the plates and sinked the glasses.	2.8125
Bob and Margaret were early so I quickly boxed the plates and sank the glasses.	2.5000

When guests come, if they arrive with slides my hopes for

a lively evening quickly sink.

When I saw Bob and Margaret carrying six boxes, 2.0625
my hopes sinked instantly.

When I saw Bob and Margaret carrying six boxes, 6.5625
my hopes sank instantly.

3. Gilligan tied the posts together with a reed.

Gilligan reeded the posts together. 4.1250

Gilligan read the posts together. (pronounce it as "red") 1.0625

Gilligan tried to read the Captain's mind.

Gilligan readed the Captain's mind. 1.0625

Gilligan read the Captain's mind. (pronounce it as "red") 7.0000

4. There is a board game in Japan called "Go",
which is very famous and popular.

But last year, chess became so popular, it out-Go'd Go. 3.5000

But last year, chess became so popular, it out-Went Go. 1.4375

I thought my son had to go to the bathroom a lot,
but that was before I took his friend along on a trip.

That little boy out-goed my son by a long shot. 1.5625

That little boy out-went my son by a long shot. 4.1250

5. Funeral directors often have to choose whether to conduct funerals,
wakes, or memorial services when families cannot decide.

Although last year they still funeraled most of the dead, 4.8750
they waked a larger number than ever before.

Although last year they still funeraled most of the dead, 2.3125
they woke a larger number than ever before.

Heavy metal rock bands often play at a volume that can wake

the dead, even though citizens complain about the noise.

Although city officials tried to get them to keep the volume down, last week they waked the dead again. 2.0000

Although city officials tried to get them to keep the volume down, last week they woke the dead again. 6.1250

6. The pennant winners didn't have to play in the first round of the playoffs; they got a bye into the second round.

The pennant winners were byed into the second round. 4.6875

The pennant winners were bought into the second round. 1.8750

The pennant winners were good enough to make it into the second round, but the Mafia managed to buy them off and they deliberately lost.

The pennant winners were buyed out of the second round. 1.2500

The pennant winners were bought out of the second round. 6.9375

7. The farmer put all his equipment in the shed for the winter.

After a couple of days, he finally shedded his tractor. 4.6875

After a couple of days, he finally shed his tractor. 2.6875

The poor farmer had to get rid of all his unnecessary equipment; to pay his debts, he had to shed himself of one possession after another.

After a couple of days, he finally shedded his tractor. 2.3125

After a couple of days, he finally shed his tractor. 5.5625

8. It's always a good idea to relax your clients by making sure they are supplied with food and drink at all times.

That's why when MacTavish arrived, I immediately snacked him, drinked him, and fed him. 2.0625

That's why when MacTavish arrived, I immediately snacked him, 1.7500

drank him, and fed him.

It's always a good idea to relax your clients by feeding them gossip and pretending to drink up the gossip they give you.

That's why when MacTavish arrived, I immediately fed him lots of gossip, and drinked up everything he said. 1.6250

That's why when MacTavish arrived, I immediately fed him lots of gossip, and drank up everything he said. 6.7500

A.3 Novel Denominal Compound vs. Novel Deverbal Compound

(The first item in each pair is denominal; the second is deverbal.)

---

1. Gretzky got a penalty for hitting the goalie with a high stick.

   Gretzky high-sticked the goalie. 5.8125

   Gretzky high-stuck the goalie. 1.9375

   Pete tried to stick the tape on the wall again and again.

   Pete re-sticked the tape on the wall. 1.6250

   Pete re-stuck the tape on the wall. 5.8750

2. The best way to make lasagna is to interleave the noodles and the spinach leaves.

   You'll like this lasagna; I interleaved the noodles and spinach carefully. 5.1875

   You'll like this lasagna; I interleft the noodles and spinach carefully. 1.6875

   Though it's important to leave your lover now and again to make him appreciate you, don't overdo it.

   Mary over-leaved him, so her lover ditched her for good. 1.3125

   Mary over-left him, so her lover ditched her for good. 3.3125

3.	Though the Big Sleep is a very popular cult movie, Citizen Kane has been accumulating quite a cult following of its own.	
	Citizen Kane may have even out-Big-Sleeped the Big Sleep.	2.9375
	Citizen Kane may have even out-Big-Slept the Big Sleep.	2.5625
	Back at the frat house, everyone is trying to oversleep more times a week than everyone else.	
	Last week, I out-oversleeped everyone.	1.6250
	Last week, I out-overslept everyone.	5.6250
4.	Pitcher Roger Clemens allowed the Orioles only three hits in the entire game.	
	He three-hitted them for the second time this season.	3.1250
	He three-hit them for the second time this season.	4.4375
	Babe Ruth had a tendency to hit the bat slightly under the balls pitched to him.	
	Babe Ruth underhitted the ball for the second time that game.	1.6250
	Babe Ruth underhit the ball for the second time that game.	5.5625
5.	Martina Navratilova beat Chris Evert in two sets.	
	Martina two-setted Chris for the fifth time in her career.	4.3125
	Martina two-set Chris for the fifth time in her career.	3.1875
	He set the table, expecting two guests to arrive.	
	When they called and canceled, he unsetted the table.	1.7500
	When they called and canceled, he unset the table.	5.1250
6.	These billboards advertising every brand of cigarettes, from Marlboroughs to Lucky Strikes, have been	

in our faces the whole trip.

We've been Lucky-Striked so many times we know the ad by heart.	3.3750
We've been Lucky-Struck so many times we know the ad by heart.	2.8750

To get a really loud tone from this bell, you've got to strike it from underneath.

See the way I understriked it? Do it like that.	2.3125
See the way I understruck it? Do it like that.	5.3125

7. The actor William Hurt has a reputation for attracting the most female autograph-seekers on the set during shooting, but this time Robert Redford attracted an even larger crowd.

Redford finally out-Hurted Hurt.	3.8125
Redford finally out-Hurt Hurt.	3.5625

The actor Sean Penn has a reputation for attacking nosy reporters and photographers in public places, but this time Jack Nicholson managed to hurt even more reporters.

Nicholson finally out-hurted Penn.	1.8750
Nicholson finally out-hurt Penn.	3.6875

8. Both boxers managed to land heavy blows on each other.

But Tyson out-blowed his opponent and won easily.	2.8125
But Tyson out-blew his opponent and won easily.	3.0000

Both women managed to blow hundreds of soap bubbles.

But Sheila outblowed her opponent and won the contest easily.	2.1875
But Sheila outblew her opponent and won the contest easily.	6.4375

9. He put an apple on his son's head, and tried to pull a William Tell.

He did it! He William-Telled the apple without touching a hair.	5.0000
He did it! He William-Told the apple without touching a hair.	1.5000

Story-telling was one of Alex's strongest points.

He story-telled the children for a solid two hours the other day.	1.6250
He story-told the children for a solid two hours the other day.	2.6250

10. Janet was fed up with her husband Sam's recurring flings
with pretty young women, four at last count.

For revenge she got a job where she could meet lots of men and after finding her fifth willing partner she had actually out-flinged the guy.	3.3125
For revenge she got a job where she could meet lots of men and after finding her fifth willing partner she had actually out-flung the guy.	3.6250

Janet was fed up with her husband Sam's habit of flinging his
dirty clothes wherever he wanted.

To show him what a mess he was making she started flinging her clothes around too, and in a day she had actually out-flinged the guy.	3.7500
To show him what a mess he was making she started flinging her clothes around too, and in a day she had actually out-flung the guy.	4.8750

11. In that movie, Charlie Chaplin did the best double-takes I've ever seen.

He double-taked every time the cop came over to him.	3.8125
He double-took every time the cop came over to him.	3.0625

If you want to keep costs down, you've got to control students
who take double helpings of the main course.

So many students double-taked last night that we quickly ran out of shrimp.	1.5000
So many students double-took last night	3.9375

that we quickly ran out of shrimp.

12. I've had so many light beers I'm sick of them
I don't think I could possibly drink another one.

As far as beers are concerned, I'm totally lighted-out.	3.8125
As far as beers are concerned, I'm totally lit-out.	2.2500

The stewardess had been trying to light up her face with a smile
so much that day, she couldn't do it one more time.

As far as her smile was concerned, she was totally lighted-out.	2.6250
As far as her smile was concerned, she was totally lit-out.	3.6250

13. The best football teams are those that are meaner on the field
than their opponents.

The Dolphins were undefeated in 1974 because they out-meaned the rest of the teams in the NFL.	3.1875
The Dolphins were undefeated in 1974 because they out-meant the rest of the teams in the NFL.	1.4375

The most successful religious leaders are those that pack the most
meaning into the fewest words.

Billy Graham was the most successful evangelist in the 1960's because his sayings out-meaned those of his rivals.	1.3750
Billy Graham was the most successful evangelist in the 1960's because his sayings out-meant those of his rivals.	3.8125

14. Sam is always acting like a shrink, psychoanalyzing half the people
at the table. But last night we had Jonathan over,
and he analyzed ALL the people at the table.

He finally out-shrinked Sam.	3.8750
He finally out-shrank Sam.	2.5625

My wife Hilda was always washing the clothes at too high a
temperature, shrinking them beyond recognition, but we hired
a housekeeper last week who ruined six shirts in one load.

She actually out-shrinked Hilda.	2.5000
She actually out-shrank Hilda.	3.6875

15. Babe Ruth hit a line drive to center field.

It was the third time he line-drived in that game.	5.5625
It was the third time he line-drove in that game.	2.9375

Racing car drivers train themselves by driving
on a perfectly straight line painted on the track.

Sam line-drived for hours every day before entering his first race.	2.0000
Sam line-drove for hours every day before entering his first race.	4.1250

16. My six-year old son will yell "no" at me 10 or 20 times
when I try to put him to bed.

Last night, he "no'd" me once too often and I lost my temper.	5.5000
Last night, he "new" me once too often and I lost my temper.	1.1875

There's this guy that says, "Don't I know you?" every time
he bumps into me, though I know it's just a line.

Last night, he "know'd" me once too often and I just walked away.	3.1875
Last night, he "knew" me once too often and I just walked away.	4.0000

17. I've had so many milkshakes, thickshakes, and and chocolate
shakes I couldn't have another shake of any kind.

I'm completely shaked-out.	4.7500
I'm completely shaken-out.	2.0000

I've had to shake so much flour onto this countertop,
I couldn't shake another ounce.

I'm completely shaked-out.	4.0625
I'm completely shaken-out.	4.0625

18. When the dog came around scratching incessantly in the house, he decided to get rid of the dog's fleas once and for all.

He de-flea'd the dog.	5.5625
He de-fled the dog.	1.5625

When the dog came around the first time, he managed to flee, and when it came around the second time, he tried to flee again.

He re-flee'd the dog.	1.8125
He re-fled the dog.	3.1875

19. I've been to so many track-meets, I couldn't stand the thought of entering another.

I'm completely meeted out.	4.0000
I'm completely met out.	1.3125

So many dignitaries have had to meet me at airports, I couldn't stand the thought of having another one meet me.

I'm completely meeted out.	2.3750
I'm completely met out.	4.1875

20. There's a trick to making beet stew. In order to make a perfect beet stew, you have to pick out all the beets before you serve it.

The stew Mary served was a lumpy mess; she never de-beeted it.	4.9375
The stew Mary served was a lumpy mess; she never de-beet it.	2.5000

The Cubs are a hopeless team. We had no trouble beating them, and when they challenged us to a rematch, we had no trouble beating them again.

In fact, we re-beated them without breaking a sweat.	1.5000

	In fact, we re-beat them without breaking a sweat.	3.8750
21.	I've had a banana split every day this week and I couldn't possibly eat another one.	
	I'm completely splitted out.	2.7500
	I'm completely split out.	2.6875
	I've been splitting logs every day this week; I couldn't possibly split another one.	
	I'm completely splitted out.	3.4375
	I'm completely split out.	4.2500

APPENDIX B. NOVEL VERBS FROM EXPERIMENT FOUR

16 Verbs from Carlson, et al. (1977)	Other 16 Verbs
dring/drang	clare/clore
kleed/kled	freep/frept
lang/lung	frow/frew
nake/nook	plare/plore
plive/plove	preed/pred
prail/prell	quare/quore
preet/pret	shing/shang
skive/skove	skring/skrung
skrib/skrobe	smeep/smept
snike/snoke	smend/sment
speeve/spove	spling/splung
spiff/spuff	splow/splew
sping/spang	sprink/sprunk
spoog/spug	sprow/sprew
treave/trove	strink/strunk
wight/wought	strow/strew

Table 1

Mean Ratings of Past Tense Forms by Verb Root from Experiment One

	Past Tense Form	
Verb Root	**Regular**	**Irregular**
All items		
Denominal	4.32	2.37
Deverbal	2.03	5.23
No capitalization/spelling differences		
Denominal	4.23	2.59
Deverbal	2.14	5.23
Existing denominals		
Denominal	5.23	2.42
Deverbal	1.84	6.67
Novel denominals		
Denominal	3.81	2.02
Deverbal	1.77	6.11
Novel compounds		
Denominal	4.19	2.46
Deverbal	2.21	4.32

Table 2

Mean Ratings of Past Tense Forms by Verb Root and Results of Analyses of Variance (Verb Root x Past Tense Form) from Experiment One by Phonological Subclass

		Past Tense Form	
Phonological Subclass/F- and p-values	**Verb Root**	**Regular**	**Irregular**
T/D + 0	Denominal	3.85	3.69
(hit, set, hurt, cast, shed, split, beat)	Deverbal	2.28	5.07
$F_{subj}(1,31) = 57.81^{***}$			
$F_{item}(1,6) = 23.32^{**}$			
T/D with laxing class	Denominal	3.98	1.48
(read, light, meet)	Deverbal	2.11	4.75
$F_{subj}(1,31) = 98.14^{***}$			
$F_{item}(1,2) = 7.89, p = .107$			
Overt-T ending	Denominal	3.65	2.11
(buy, leave, mean, sleep)	Deverbal	1.47	5.16
$F_{subj}(1,31) = 113.03^{***}$			
$F_{item}(1,3) = 32.06^{*}$			
Overt-D ending	Denominal	5.28	1.53
(flee, tell)	Deverbal	1.72	2.91
$F_{subj}(1,30) = 79.13^{***}$			
$F_{item}(1,1) = 127.37, p = .056$			

E-ɔ ablaut class	Denominal	5.27	1.80
(steal, break, wake)	Deverbal	1.80	6.42
$F_{subj}(1,31)$ = 282.27***			
$F_{item}(1,2)$ = 82.93*			
I - ae/^ - ^ group	Denominal	3.97	2.57
(strike, ring, drink, sink, shrink, stick, fling)	Deverbal	2.20	5.59
$F_{subj}(1,31)$ = 248.00***			
$F_{item}(1,6)$ = 21.85**			
x - u - x/o+n	Denominal	4.52	2.33
(know, fly, blow)	Deverbal	2.59	5.33
$F_{subj}(1,31)$ = 31.58***			
$F_{item}(1,2)$ = 145.55**			
e - U - e+n	Denominal	4.28	2.53
(shake, take)	Deverbal	2.78	4.00
$F_{subj}(1,30)$ = 22.04***			
$F_{item}(1,2)$ = 184.18*			
ay - o - I+n	Denominal	5.69	2.16
(drive, write)	Deverbal	1.53	5.47
$F_{subj}(1,30)$ = 228.18***			
$F_{item}(1,1)$ = 31.88, p = .222			

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

Table 3

Mean Ratings of Past Tense Forms by Verb Root from Experiment Two

	Past Tense Form	
Verb Root	**Regular**	**Irregular**
All items		
Denominal	4.94	3.36
Deverbal	1.96	6.45
No capitalization/spelling differences		
Denominal	4.84	3.68
Deverbal	2.17	6.53
Existing denominals		
Denominal	5.84	2.53
Deverbal	2.06	6.97
Novel denominals		
Denominal	4.41	3.59
Deverbal	1.53	6.69
Novel compounds		
Denominal	4.80	3.56
Deverbal	2.09	6.16

Table 4

Percentage of Irregular Past Tense Responses in Carlson, Keyser & Roeper (1977)

	Presentation Context		
Novel Verbs	**Basic Verb**	**Deverbal Noun**	**Basic Noun**
dring	46.7	60.0	33.3
kleed	28.3	26.7	20.0
lang	16.7	6.7	6.7
nake	5.0	0.0	6.7
plive	25.0	23.3	3.3
prall	3.3	0.0	0.0
preet	11.7	10.0	3.3
skive	21.7	20.0	6.7
skrib	10.0	3.3	0.0
snike	5.0	20.0	10.0
speeve	6.7	23.3	13.3
spiff	6.7	6.7	3.3
sping	58.3	33.3	23.3
spoog	8.3	3.3	6.7
treave	16.7	10.0	10.0
wight	36.7	10.0	16.7
Overall	19.3	16.0	10.2

Table 5

Mean Rating of Past Tense Forms from Experiment Five

	Presentation Context		
Past Tense Form	**Basic Verb**	**Deverbal Noun**	**Basic Noun**
Regular	4.38	4.24	4.34
Irregular	5.13	4.94	4.60
Irregular - Regular	0.75	0.69	0.16

Figure Caption

Figure 1. Mean ratings for regular and irregular items as a function of whether the verb was derived from a verb or a noun; data from Experiment 1 (MIT Undergraduate subjects).

Figure 2. Mean ratings for regular and irregular items as a function of whether the verb was derived from a verb or a noun; data from Experiment 2 (non-college-educated subjects).

Figure 1.

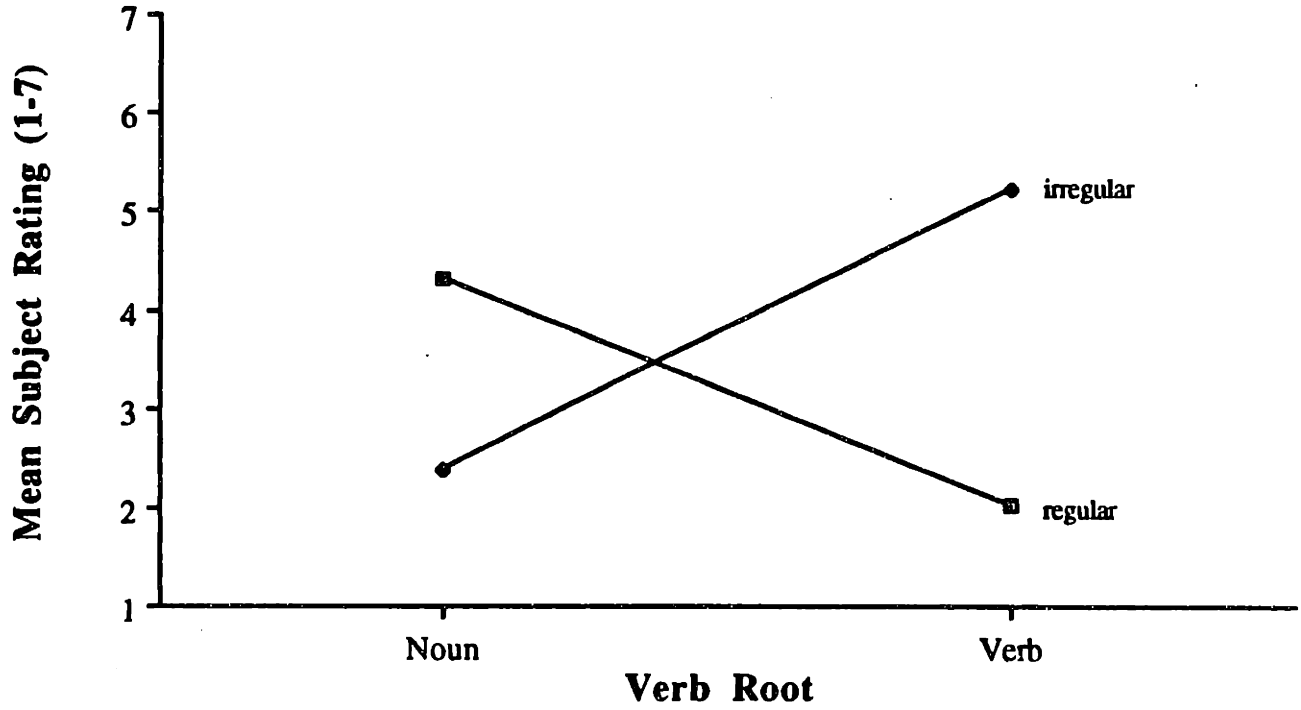
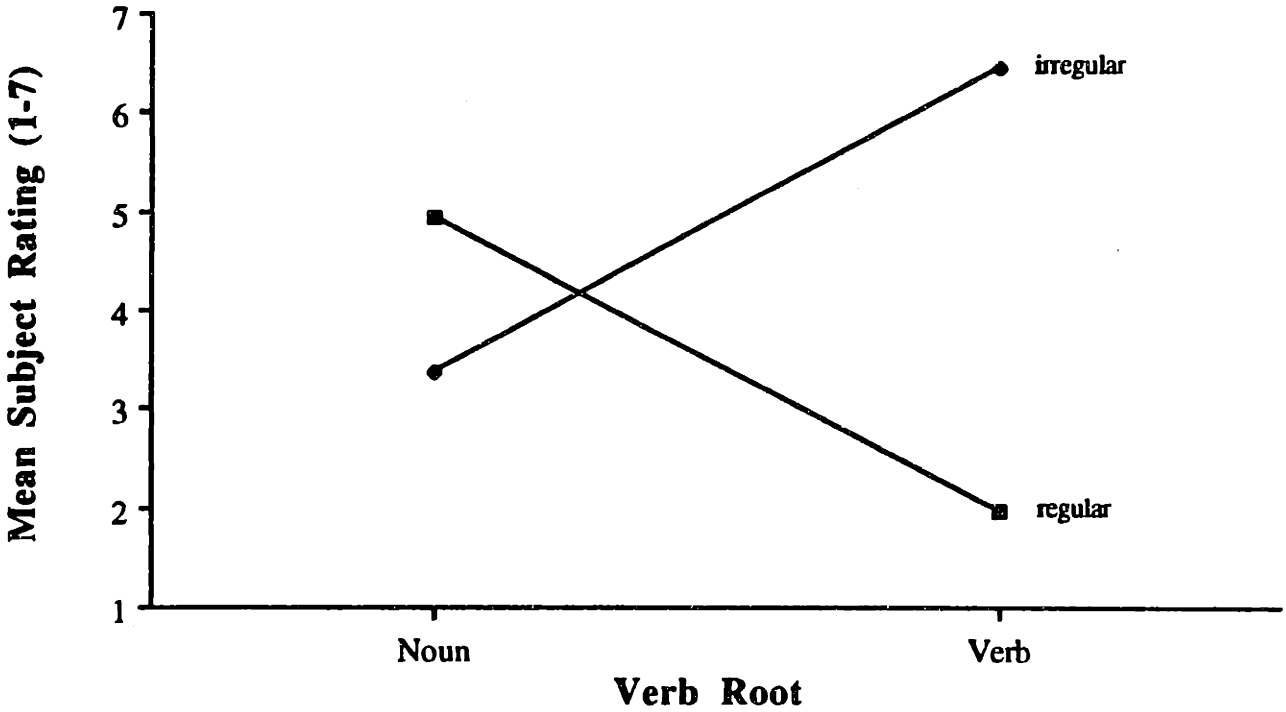

Mean Subject Rating (1-7)
7
6
5
4
3
2
1
irregular
regular
Noun
Verb
Verb Root

Figure 2.


Mean Subject Rating (1-7)
7
6
5
4
3
2
1
irregular
regular
Noun
Verb
Verb Root

CHAPTER 2

Sensitivity of Children's Inflection to Grammatical Structure[12]

[12]Kim, J. J., Marcus, G. F., Pinker, S., Hollander, M. & Coppola, M. (in press). Sensitivity of Children's Inflection to Grammatical Structure. *Journal of Child Language.*

Introduction

Linguistic research during the past 25 years has sketched out the general logic by which word forms are constructed and coordinated with sentences (Chomsky & Halle, 1968; Aronoff, 1976; Lieber, 1980; Williams, 1981; Selkirk, 1982; Kiparsky, 1982a, 1982b, 1983; Bybee, 1985; Anderson, 1992; see Spencer, 1990, for an introduction, and Beard & Szymanek, 1988, for a bibliography). The morphological component of the human language system seems to contain a lexicon of stored word roots, a set of derivational rules that create new word forms from old ones, and a set of inflectional rules that modify a word's form according to its role in the sentence (e.g. tense and number). Derived and inflected words are mentally represented as complex data structures. These structures contain symbols that express the formal grammatical categories (noun, verb, adjective, etc.) of the roots that went into forming the word, the grammatical category of the word as a whole, and a tree structure interconnecting these symbols that reflects the rules that went into building the word form. For example, the adjective *learnable*, derived by combining the verb root *learn* with the adjectival affix *-able*, would be represented as $[\text{learn}_V \text{ -able}_{Adj}]_{Adj}$. Though the particular rules and word forms vary from language to language, the overall architecture of this system is widely seen across languages.

The organization of morphology has implications for the acquisition of morphology. Understanding language acquisition requires specifying the innate mechanisms that accomplish language learning, and the language-particular information that these mechanisms learn. It has been fruitful to posit that the universal basic organization of grammar is inherent in the learning mechanisms, which are deployed to acquire the particular words and rules in a given language (e.g. Pinker, 1984, 1989). If this is correct, one might expect that the basic design of morphology should be visible in children's linguistic behavior as they are learning language.

comment{David: more or less below:}

But many psychologists have been reluctant to accept abstract linguistic categories and structure as part of the child's learning mechanisms and knowledge of language. Recently an alternative has become envisionable. Connectionist or Parallel Distributed Processing (PDP) models consist of networks of densely interconnected units whose connection strengths are adjusted during an extensive training schedule (Rumelhart & McClelland, 1986). Though these models are compatible in principle with abstract

grammatical categories, structured representations, and multiple components, in practice PDP language modelers (e.g. Rumelhart & McClelland, 1986; Plunkett & Marchman, 1990, 1991; MacWhinney & Leinbach, 1991; Seidenberg & Daugherty, 1992; Hare & Elman, 1992) attempt to do away with them, preferring a single, homogeneous network that maps the features of an input word form (either phonological or both phonological and semantic) to the features of an output word form. Under these proposals, any sensitivity to abstract grammatical categories and structure must either be ignored, explained away, or hoped to emerge from the patterns of acquired feature-to-feature mappings.

This paper seeks to determine what kind of information -- phonological, semantic or grammatical -- constitutes the input to children's inflectional system. This is a question about the global information-flow or input-output architecture of children's language system, and is relevant to any model of children's language. Note that we will *not* be testing for differences between symbolic and connectionist architectures for language, since in principle both kinds of models could feed, or sequester, various kinds of information to the mechanism that computes inflection. It does, however, speak to the style of connectionist models that is currently popular, where the modelers attempt to avoid any design that reflects abstract grammatical categories and structure, relying on networks that map only among an innate set of phonological (and possibly semantic) features.

We begin by examining the information relevant to computing past tense and plural inflection in adults. In English, there are two types of verbs, those with a regular suffixed past tense form, such as *walk/walked, jump/jumped,* and *open/opened,* and those with an unpredictable irregular past tense form, such as *blow/blew, sing/sang,* and *break/broke.* The plural system shows a similar organization, with regular nouns like *boy/boys, cat/cats,* and *hand/hands,* and irregular nouns like *man/men, mouse/mice,* and *tooth/teeth.* New verbs and nouns virtually always receive regular inflection: *He faxed the message; She received two faxes* (Prasada & Pinker, 1993). A straightforward explanation is that a rule generates the inflected forms of regular words, but irregular forms are memorized by rote. In this simple textbook model, the information fed into the inflectional system is simply whether a word is or is not on the memorized list of irregulars. If a word has an irregular inflected form listed in the dictionary, it is retrieved; if not, the regular rule

applies.

However, this account fails to capture the fact that most irregular past tense verbs form their past tenses in ways similar to other irregular past tense verbs with similar phonological characteristics. One example is the set of irregular verbs with stems that have an *i* followed by a velar nasal consonant, such as *sing/sang*, *ring/rang*, *drink/drank*, *spring/sprang*, and *stink/stank*. Though this type of clustering by phonological properties is, to a large extent, a historical residue of the Old English strong verb classes, clusters of similar irregular past tense verbs may sometimes lend their patterns to phonologically similar new verbs, suggesting that a word's *phonological composition* is part of the input to the inflection box. We see this semi-productivity in the historical record: Several verbs have been assimilated to irregular patterns within the past several hundred years under the influence of existing clusters of similar irregular verbs (Jesperson, 1942/1961); examples include *fling/flung*, *kneel/knelt*, *quit/quit*, *sling/slung*, *stick/stuck*, and *string/strung*. By a similar process, many dialects of English have some irregular past tense forms that differ from those in the standard dialect, like *bring/brung*, which are presumably analogized from the *sling/slung* cluster. Children also occasionally use novel irregular past tense forms, like *brang* for *brought*, *bote* for *bit*, and *truck* for *tricked* (Xu & Pinker, 1992). Finally, Bybee & Moder (1983) and Prasada & Pinker (1993) showed that when adult experimental subjects are asked to produce the past tense form of a novel verb (e.g. *to spling*), the likelihood of an irregular past tense response (e.g. *splung*) increases with the phonological similarity of the novel verb to the phonological prototype of an irregular past tense cluster.

There is general agreement that phonological information must be fed into the past tense computation, but disagreement over how this information is used. Some linguists have proposed that the redundancy and partial productivity of irregular past tense clusters be handled by subregular rules (e.g. 'change [I] to [^]'), some tied to specific lexical entries, others to phonological properties of classes of items (Halle & Mohanan, 1985). Others (e.g. Lieber, 1980; Pinker & Prince, 1988, 1991; Pinker, 1991; Marcus, et al., 1992; Prasada & Pinker, 1993; Spencer, 1990) have suggested that the phonological patterns of irregular stems and their past tense forms come not from productive rules but from memory storage, where similar-sounding word pairs are superimposed in the memory representation and hence reinforce each other and enable occasional analogizing

to new similar forms. In both theories, the phonological properties of a word, together with its lexical status as an irregular, are input to the inflection system. If a word is not listed as being irregular, and if it does not engage an irregular phonological pattern by virtue of its sound pattern, it is handled by the regular suffixation rule, which acts as a default, applying to any stem that slips through the irregular filter.

Rumelhart & McClelland's (1986) PDP model of past tense inflection uses the phonological properties of stems in a different way: It uses nothing but the phonological properties of the stems as input. A base form is represented by a pattern of activation within a vector of nodes each of which stands for a phonological property of the stem (e.g. a stop consonant at the beginning of the word; a high vowel between two voiced segments). The network has an output vector with a similar structure, representing the computed past tense form of the verb. Every input node is connected to every output node by a connection with a modifiable weight. In a learning phase, the network is presented with a verb stem, represented as a set of activated input nodes, and produces an inflected form by activating a set of output nodes. A 'teacher' supplies the model with the correct past tense form for the stem, and the model adjusts the strength of the connections between the input and output nodes to minimize the difference between its computed output form and the correct past tense form. After the learning phase, the network can reproduce the past tense forms of the verb stems that it was trained on, and can generalize to many novel verbs on the basis of their phonological similarity to the verbs in the training set. Thus the model performed the stem-to-past tense mapping solely on the basis of phonological information. It captured patterns of phonological similarity for regulars and irregulars alike, generalizing in similar ways from *step* to *stepped* and from *cling* to *clung*. The model makes no qualitative distinction between irregular (lexically stored) and regular (rule-generated) past tense formation, and hence needs no information in its input to indicate the irregular status of irregular verbs. Nor did it implement formal linguistic notions such as 'verb root', 'rule', and 'lexical item'. Thus the model is often characterized as an alternative to symbol-processing or rule-based accounts of the acquisition and knowledge of language.

Does the Rumelhart-McClelland model show that the only information necessary for computing past tense forms is the phonology of the stem? Pinker & Prince (1988) and Kim, Pinker, Prince, & Prasada (1991) have shown why that cannot be true for

adults. First, some pairs of verbs, such as *ring/rang* and *wring/wrung*, have homophonous stem forms but different past tense forms.

(1)	a.	Muddy *rang* the bell.	*ring/rang*
		Muddy *wrung* the washcloth dry.	*wring/wrung*
	b.	T-Bone *lay* on his bed.	*lie/lay*
		T-Bone *lied* to me again.	*lie/lied*
	c.	B.B. first *met* Jimmie in 1975.	*meet/met*
		B.B. gradually *meted* out favors to his roadies.	*mete/meted*
	d.	Buddy's voice *sank* two octaves.	*sink/sank*
		Buddy *synched* his voice track to his guitar track.	*synch/synched*

Thus homophonous verbs must be given nonidentical representations when they enter into the process that generates past tense forms. The representation called a 'lexical entry' captures this distinctness -- each verb in the pairs above has its own lexical entry, which has the possibility of having an irregular past tense form linked to it; if not, the regular process applies.

Note that while different lexical entries are different in meaning, this does not imply that semantic information is input directly into the past tense formation process, as MacWhinney and Leinbach (1991) claim when they redesigned the PDP past tense learning model in response to the homophone problem.[13] But such a solution has additional consequences which have to be taken seriously. Hinton, McClelland & Rumelhart (1986) note what happens when features of a particular kind are input to a parallel distributed processing model: 'one of the most interesting properties of distributed representations [is that] they automatically give rise to generalizations' (p. 82); 'any subset of the microfeatures can be considered to define a type. ... This allows an item to be an instance of many different types simultaneously.' (p. 84) But this is exactly what does not happen with homophone pairs with different past tense forms. The

[13]In their discussion, MacWhinney & Leinbach (1991) concede the need for a lexicon with distinct entries. They do not, however, implement such a lexicon in their model, and we will discuss the model itself.

semantic features differentiating *wring* from *rung*, *meet* from *mete*, and so on, do not in general differentiate different types of past tense forms: Verbs with meanings similar to *wring* do not tend to have past tense forms with *-ung*, and verbs with meanings similar to *ring* do not tend to have past tense forms with *-ang*. The semantic differences between homophones with different past tense forms are haphazard and idiosyncratic to the particular pair of verbs. This shows that speakers may use semantics to tell which of two lexical entries they are dealing with, but it is the lexical entry itself that is fed into the past tense formation process, not the semantic features directly.

A second and more systematic class of homophones with different past tense forms implicates a categorical difference between regular and irregular inflection. Irregular past tense forms are stored in the mental dictionary: They are linked to *verbs root* -- the irreducible form-meaning pairing that defines the basis of a family of verbs. Only if a verb is based on an irregular verb root will that verb have an irregular past tense form. Regular past tense formation, in contrast, has the status of a default operation -- it applies in all circumstances where an irregular verb root is not available (Pinker & Prince, 1988, 1991; Pinker, 1991; Marcus, Brinkmann, Clahsen, Wiese, Woest, & Pinker, 1993). Thus, the input to the past tense system must include information as to whether a word is based on an irregular root -- that is, information about its *morphological structure*. This fact has several implications.

A denominal verb is a verb that is sensed by speakers to be derived from or based on a noun. Denominal verbs (and verbs based on other categories, like adjectives or prepositions) uniformly have regular past tense forms, regardless of their phonology or semantics. Indeed, even if a denominal verb is homophonous with an irregular verb, it will be regular, a phenomenon first noted by Mencken (1936) and given an explanation by Kiparsky (1982a, 1982b). Examples are shown in (2); (a) and (b) are due to Paul Kiparsky; (c)-(j) are from Pinker & Prince (1988).

(2) a. He *grandstanded* to the crowd.	**grandstood*
b. He *flied out* to center field.	**flew*
c. He *spitted* the pig.	**spat*
d. He *ringed* the city with artillery.	**rang*
e. Martina *2-setted* Chris.	**2-set*
f. He *righted* the boat.	**rote*

g. He *high-sticked* the goalie. **high-stuck*

h. He *braked* the car suddenly. **broke*

i. He *sleighed* down the hill. **slew*

j. He *de-flea'd* his dog. **de-fled*

k. He *steeled* himself for the ordeal. **stole*

l. The doctor *casted* his leg. **cast*
(relayed by Lila Gleitman and Stephen Kosslyn)

m. Vera *costed* out the equipment requests in the grant proposal for us. **cost*
(relayed by Alan Prince)

n. I *big-ringed* it the rest of the way. **big-rang*
(used the big chain ring while bicycling; from a bicycle magazine).

o. In each of the past two seasons, Cleveland State guard William Stanley has sported a self-styled, one-of-a-kind hairdo. In 1987-88 it was a half-foot-high flattop. Last season he went to a bilevel box cut. This season, as a senior, Stanley has *outdo'ed* himself. **out-done*
(Sports Illustrated, 12/6/89)

p. You mean this list, and you mean that list, and after you've *meaned* both lists .... **meant*
(from statistics lecture; relayed by Annie Senghas)

q. Most snow or sugar snap [peas] need to be '*stringed*'. To string, pinch the top and pull the string along the flat side to the stem end. **strung*
(from the food section of The Boston Globe, June 26, 1991.)

r. We to *be'd* or not to *be'd* for hours on end. **were*
(Jane Austin, Mansfield Park, Chapter 13; relayed by Karin Stromswold.)

What these examples have in common is that the verbs are not directly constituted

of verb roots; they are transparently based on nouns, adjectives, or phrases (the rough meanings in (3) correspond to the respective examples in (2)):

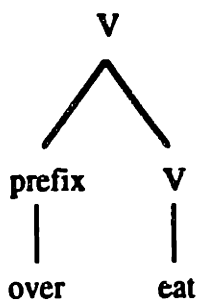
(3) a. to play to the *grandstand*
b. to hit a *fly* (ball) that gets caught (in baseball)
c. to put on a *spit*
d. to form a *ring* around
e. to beat in two *sets*
f. to set *right*
g. to hit with a *high stick*
h. to apply the *brakes*
i. to travel in a *sleigh*
j. to remove *fleas*
k. to cover, point, or face with *steel*; to make as hard as *steel*
l. to put a *cast* on
m. to ascertain the *costs* of
n. to pedal with the chain on the *big ring*
o. to affect a more impressive hair-*do* than
p. to calculate the *mean* of
q. to remove the *string* from
r. to say '*to be or not to be*'

Though homophonous with irregular verbs, these verbs have regular past tense forms because irregularity is a property of verb roots, not of verbs, and these verbs have noun roots or adjective roots, not verb roots. A noun like *ring* cannot have an irregular past tense associated with it because a noun cannot have any past tense associated with it, the notion of 'past tense' making no sense for a noun. The regular inflectional rule, being the default, is the only way to inflect such derived verbs.

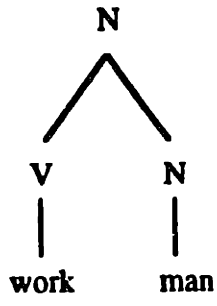
Regularization of denominal verbs is part of a more general phenomenon whereby the morphological structure of a verb determines its semantic, syntactic, and inflectional properties (Williams, 1981; Selkirk, 1982; Kim, et al., 1991; Pinker & Prince, 1991). In the constituent structure reflecting a word's derivation from more basic morphemes, one of these morphemes is generally the *head* of the word, and its properties percolate up to

the word as a whole. In English, the head of the word is generally the rightmost element. Thus the head of *overeat*, whose structure is given in (4a), is the verb *eat*, so *overeating* is a kind of *eating*, and it is a verb just as *eat* is a verb. Similarly, a *workman*, whose structure is given in (4b), is a noun referring to a kind of man, not a kind of work.

(4) a.



b.

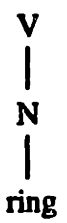


The conduit for information flow from the head to the top node of a word structure applies to *all* the information stored with the head (see Spencer, 1990, for qualifications to this statement, which are not relevant here). Not only does the grammatical category and meaning of the head percolate up (together with features like gender, humanness, animacy, and inherent aspect), but for irregular words, the irregular past tense or plural form stored with the head percolates up as well. Thus the past tense of *overeat* is *overate*, and the plural of *workman* is *workmen*. This is also why we get irregularity preserved in novel forms like *out-sang, overshot, sawteeth, oil-mice* (Chinese peasants who scavenge uncollected oil from wells), *took a leak, blew him away, came into money*, and so on. Note that neither novelty, nor, as we shall see, metaphoricity, prevents these forms from being irregular, as long as they have an irregular head.

Some words, however, are headless, or 'exocentric': They differ in some property from their rightmost element, requiring that the usual pipeline of information from head to top node be blocked. For example, the structure in (5a), corresponding to the verb *ring* from *ringing the city*, shows a verb derived from a noun. Since the whole word, represented by its topmost label, is a verb, but the element it is made out of, *ring*, is a noun, it must be headless or 'exocentric' -- if the noun *ring* were its head, *to ring* would have to be a noun, too, which it is not. Lacking a head and its associated data pipeline, the irregular form of the verb *to ring*, namely *rang*, cannot percolate up to attach to the

whole word. The regular *-ed* rule applies in its usual role as the last resort, and thus we get *ringed.*

(5) a.



b.

Note that this machinery also operates in the verb *to fly out*, whose structure is given in (5b), even though the noun it comes from, *fly (ball)* (i.e. 'a baseball hit high in the air'), itself originally came from the verb *to fly* (i.e, 'to proceed through the air'). The step in the derivation that derives the verb *(to fly out)* from the noun *(fly ball)* yields an exocentric structure, as does the step in the derivation that derives the noun *(fly ball)* from the root verb *(fly)*. Therefore, the derived verb has no head and, consequently, has no pathway for the irregularity of its root to percolate up to the top node representing the word as a whole. What kills the irregularity of *fly out*, then, is not its specialized meaning, but its being a verb based on a word that is not a verb.

Interestingly, the theory that explains regularization by exocentrism is sufficient to explain several seemingly unrelated cases in the plural system of nouns as well, even ones where there is no category change. Consider *low-life* -- not a kind of life at all, but a kind of person, namely one who leads a low life. This is an exar ple of a 'bahuvrihi' compound, a compound that refers to an object characterized by *having* rather than *being* the referent of its rightmost morpheme. Recall that the head-to-top-node pipeline cannot be blocked for just one kind of information; if it is blocked for one thing, nothing passes through automatically. That means that there is no way for the irregularity of the root of a headless word to percolate up: If *low-life* cannot get its referent from *life*, it cannot get its plural from *life* either. When the irregular is unavailable, the all-purpose regular rule, 'add *-s*,' steps in by default. This explains why people judge its plural to be *low-lifes*, not *low-lives*. Other examples of regularized exocentric compounds (sometimes co-existing

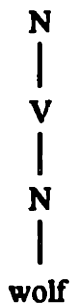
with the irregular form) include:

(6) a. We enjoyed the art gallery that displayed the *still lifes* more than any other gallery we visited.	**still lives*
b. People used to wonder if Bigfoot even existed; now they think there are several *Bigfoots*.	**?Bigfeet*
c. I used to like the police until the *flatfoots* kept pulling me over for speeding.	**?flatfeet*
d. Last year, the cub scouts went camping; but this year, the *tenderfoots* are going white water rafting.	**?tenderfeet*
e. The *goofy-foots* forgot to bring their surfboards. (slang for inexperienced or left-footed surfers; relayed by Karin Stromswold and Annie Senghas)	**?goofy-feet*
f. The *proudfoots* were creatures from Tolkien's The Fellowship of the Ring. (relayed by Elliza McGrand)	**?proudfeet*
g. I've played a practical joke or two in my lifetime but the greatest *hotfoots* are by my sister.	**hotfeet*
h. More and more *bigmouths/loudmouths* (unvoiced *th*) have been on television talk shows over the past ten years.	*voiced *th*
i. I have two Sony *Walkmans;* one for recording lectures and talks and one for listening to music.	*?Walkmen*
j. There was a display of a family of *saber-tooths* at the museum.	**saber-teeth*
k. My favorite cartoon feline from the 1970's was Snaggle-tooth. I wish there were more *Snaggle-tooths* on TV today.	**Snaggle-teeth*

A third regularization phenomenon receives a similar explanation. Just as verbs derived from nouns are exocentric and hence take regular past tense forms even if homophonous with irregular verbs, nouns derived from verbs are exocentric and take regular plural forms even if homophonous with irregular nouns. The structure in (7)

corresponds to the example in (8a).

(7)



(8) a. The boys always wolf down their food; with a couple of quick *wolfs*, they consumed their sandwiches.	**wolves*
b. While we're at the conference in Maine I hope we'll have time between sessions for a couple of quick *fishes*.	**fish*
c. During the last faculty meeting Harold gave Sam a few *knifes* in the back.	**knives*
d. He reached over and gave her a couple of quick playful *gooses*.	**geese*
e. I need to find some examples of splashy perfume ads; can you take this magazine and do a couple of quick *leafs* through it?	**leaves*

A fourth regularization phenomenon involves nouns derived from names. When a proper name (which ordinarily cannot be pluralized at all) is converted to a common noun, the result is exocentric. That is because the name of an individual is semantically ineligible to bear a plural feature, and because a noun derived from it is not an example of the kind of thing referred to by the name (see Marcus, et al., 1993, for further explanation). The resulting N dominating a name takes a regular plural. The structures in (9a) and (9b) correspond to the examples in (10a) and (10b), respectively.

(9) a.

b.

(10) a. We're having Julia Child and her husband over for dinner. You know, the *Childs* are really great cooks.	**Children*
b. I keep telling my father to buy a Mercedes, but he insists that with that kind of money he could buy several *Renault Elfs*.	**Renault Elves*
c. I'm sick of all the *Mickey Mouses* that have been running this country for the past 12 years.	**Mickey Mice*
d. The *Toronto Maple Leafs* are sure to be one of the best hockey teams in the NHL this year again.	**Toronto Maple Leaves*
e. The number of tractors a farmer has is a good way to tell how much land he farms. We have five *John Deeres* on our farm.	**John Deere*
f. There are way too many *Thomas Manns* in the literary world today.	**Thomas Menn*
g. I like all versions of *Pretty Woman*, but Roy Orbison's original version is clearly the best of all the *Pretty Womans*.	**Pretty Women*
h. Many blues artists emulate Muddy Waters, but there aren't that many *Howlin' Wolfs* on the blues scene today.	**Howlin' Wolves*
i. He's the best of the *Mac the Knifes* in this run	**Mac the Knives*

of Beggar's Opera.

j. Movie sequels are really getting out hand; there are two *Batmans* and who knows how many *Supermans* there are. **Batmen* **Supermen*

Other cases in English that follow this principle include nouns derived from verb phrases (e.g. *I bought two bag-a-leafs/*bag-a-leaves*) and quoted nouns (e.g. *While checking for sexist usage, I found three 'mans'/*'men' on the first page*). Indeed, the prediction of the grammatical-structure theory is that *any* circumstance in which a word is sensed not to be headed by a root in the language will cause the word to have a regular inflected form, regardless of its phonology (see Marcus, et al., 1993).

Note that just as specific semantic features are not relevant to a word's inflectional status as either regular or irregular, the global degree of concreteness versus abstractness, literalness versus metaphoricity, or centrality versus extendedness of word sense does not predict regularization either, contrary to the suggestions of Lakoff (1987) and Harris (1992). Exocentric words are generally extended in meaning, but it is the exocentrism itself that causes regularization. Words that are extended in meaning without being exocentric do not predictably regularize, as in *chessmen/*chessmans, oilmice/*oilmouses, sawteeth/*sawtooths, metrical feet/*foots, leaves/*leafs of the book, Freud's intellectual children/*childs*, and so on, and in verbs like *cut/*cutted a deal, blew/*blowed him off, took/*taked a leak, caught/*catched a cold, put/*putted him down, came/*comed off well, went/*goed crazy*, and hundreds of others (Pinker & Prince, 1988).

In sum, five kinds of information could, in principle, feed into the computation of a word's inflectional form: Its lexical entry, phonological composition, semantic features, morphological structure, and degree of semantic extendedness. The simplest textbook model has the lexical entry as the sole input. The Rumelhart-McClelland model has phonological composition as the sole input. The MacWhinney-Leinbach model has phonological composition and semantic features as the input. Lakoff and Harris suggest that the input includes some representation of semantic extendedness. And theories from generative linguistics have morphological structure, which incorporates the lexical entry, as the input (with a minor role for phonological composition in analogies to novel irregular forms, though only if they involve an irregular root in head position).

Previous Studies

In an experiment with 32 college students, Kim, et al. (1991) investigated the role of phonology, grammatical structure, and semantic extendedness in adults' generalizations of past tense inflection. Subjects were asked to rate regular and irregular past tense forms of denominal and extended verbs which were homophonous with irregular verbs. An example is given in (11) and (12):

(11) *Denominal*: It's always a good idea to relax your clients by making sure they are supplied with food and drink at all times. That's why when MacTavish arrived, I immediately snacked him, drinked/drank him, and fed him.

(12) *Extended*: It's always a good idea to relax your clients by feeding them gossip and pretending to drink up the gossip they give you. That's why when MacTavish arrived, I immediately fed him lots of gossip, and drinked/drank up everything he said.

The findings supported the grammatical structure theory and not the phonology-only theory: Subjects rated regular past tense forms as better than irregular past tense forms for denominal verbs, but irregular past tense forms as better than regular past tense forms for extended verbs. These results were replicated with noncollege-educated adults, showing that the effect is not a consequence of formal language training that the college subjects might have received. Kim, et al. also collected data showing that semantic extendedness cannot explain these results (to be discussed later).

In this paper, we present four experiments aimed to test whether children, too, are sensitive to formal grammatical structure. We look for differences in the way children inflect verbs which are homophonous with irregular verbs, and nouns which are homophonous with irregular nouns, by varying their paths of morphological derivation.

Note that we are only able to test whether children's behavior in using inflections is *sensitive* to morphological structure, not whether it is *determined* by morphological structure. Children's behavior is the result of a multitude of factors, their knowledge of language being only one of these. In fact, Marcus, et al. (1992) found that children's behavior in experiments eliciting past tense and plural forms is subject to a variety of nongrammatical factors. These factors cause children to produce overregularizations like *comed* between 10% and 55% of the time, far greater than their error rate in spontaneous speech, which generally averages from 2% to 4%. Children might overregularize in

experiments for several reasons: because they are under performance pressure; because they have recently been primed with the stem in the elicitation instructions (e.g. *This is a girl who knows how to swing; She did the same thing yesterday; Yesterday, she* _____), leading them to include the stem as part of an overregularized response like *swinged*; or because they fall into a strategy of failing to attend to the word as a word to be looked up in the mental dictionary, treating it instead as a pure sound, which thereby calls for the regular rule. In the experiments we report here, attentional factors could also produce the opposite contaminant: If children are not paying attention or neglect the context we provide that defines a word as exocentric for any other reason, they could treat it as the original word, and therefore fail to regularize it as its grammatical structure would demand. Because we cannot control the strategic and performance factors that can lead to regularization or lack of regularization across the board, we can only point to *differences* in regularization rates between items differing in grammatical structure, and can therefore only test whether information of a particular sort is part of the input to the inflectional process, not whether it is the sole input.

Experiment One

If children are designed with only phonological composition as the input to their inflectional process, as the Rumelhart-McClelland model and several of its successors assume, then all verbs that are homophonous with irregular past tense verbs will have an irregular past tense form, because there is in principle no way the process can distinguish among phonologically identical verbs. If children are designed with grammatical structure as the input to their past tense system, then verbs with irregular verb roots in head position will have an irregular past tense form, but denominal verbs, lacking a verbal head, will have a regular past tense form, even if they are ultimately related to some irregular verb root. The first experiment tested these predictions with six- to nine-year-old children.

Method

Subjects. Twelve children ranging in age from 6;8 to 8;10 (mean 7;4) were drawn from a summer day camp.

Materials. Nine irregular verbs were used: *see, buy, meet, drink, fly, stick, write, leave, ring*. Each item was used twice, once as a verb root and once as a denominal verb. The grammatical structure of the verb was implied to the children by using the stem initially either with the usual meaning of the verb, or with the meaning of the homophonous noun. An example of the denominal and verb root pairs is shown in (13) and (14). Appendix A provides a full list of the experimental materials.

(13) *Denominal*: This is a fly. Can you say 'This is a fly?' I'm going to fly this board. <put flies all over the board> I just __.

(14) *Verb Root*: This airplane is going to fly. Can you say 'This airplane is going to fly?' This airplane is about to fly through the air. <have the airplane fly about> The airplane just __.

Design and Procedure. Children were presented with all 18 examples in one of four orders. The first was constructed at random. The second replaced each denominal item in the first version with its verb root counterpart, and each verb root item with its denominal counterpart. The third and fourth orders were the reverse of the first and second. Three children were presented with each of the four orders.

The children's responses were tape-recorded. Children occasionally changed their minds; their initial responses and their final ones were tallied separately. Because a child's first reaction might be based on a surface phonological association, the final response was counted as the definitive datum in the analyses reported. However, the means and the results of the significance tests are very similar in all cases when the first response rather than the final response is counted. Responses were coded as *regular, irregular, no change* (when the child simply repeated the stem form), or *uncodable* (for all other response types). No-change responses were not counted as irregular, even though the past tense forms of some irregular past tense verbs involve no phonological change to the stem (e.g. *hit, cut, put, set*), because none of the verbs used in this study were of that type.

Results

The data are summarized in Table 1. Two Analyses of Variance (ANOVAs) were performed on the final verb responses that were either regular or irregular. In the first, the random variable was Subjects; the independent variables were Order and

Morphological Structure (Denominal versus Verb Root); the dependent variable was the proportion of the child's responses (not counting no-change and uncodable responses) that consisted of regularly inflected forms (i.e. number of regular responses/[number of irregular responses + number of regular responses]). The main effect of morphological structure was significant; $F(1,8) = 94.75$, $p < .001$. The second analysis had Items as the random variable, and morphological structure as the only independent variable. Again morphological structure exerted a significant effect; $F(1,8) = 59.07$, $p < .001$. That is, of the clearly regular and clearly irregular final verb responses, children responded with regular past tense forms more often than irregular past tense forms for denominal verbs, and with irregular past tense forms more often than regular past tense forms for verb roots.

Insert table 1 about here

Furthermore, for each subject the proportion of the regular and irregular responses that was regular was greater for denominal items than for items in the verb root condition. This was true over items as well: For each denominal/verb-root pair of items, the proportion of the regular and irregular responses that was regular was greater for the denominal item than for the verb root item.

Discussion

Children between the ages of six and nine gave regular past tense forms for verbs that are derived from nouns even when their homophonous verb root counterparts have irregular past tense forms that the children know. The experimental results are consistent with the hypothesis that children of this age are sensitive to the morphological derivation of verbs.

As mentioned, it is not possible to determine why children provided irregular forms for denominal items 17.6% of the time. There are many possible reasons. Perhaps children's inflectional systems are inherently probabilistic; perhaps children's attention to the denominal context in this experiment was probabilistic; perhaps children were

probabilistically reluctant to respond with regular past tense forms for the experimental items just because they consciously realized that the regular past tense form is 'incorrect' for the homophonous verb root with which they are familiar (a metalinguistic process that occasionally dilutes derivation effects in adults as well; see Pinker & Prince, 1988; Kim, et al., 1991). In any case, we see a strong effect of morphological structure in the predicted direction above these potential sources of noise.

Experiment Two

Although Experiment 1 showed that children do not rely solely on phonology to compute past tense forms, it is premature to claim that they represent morphological structure and a difference between regular and irregular past tense formation. First, these are school-age children, and it is possible that their grammatical systems underwent some kind of reorganization after the basis of language acquisition had been laid down, possibly in response to literacy and schooling. It is virtually certain that they did not explicitly learn in the classroom that denominal verbs have regular past tense forms, because this phenomenon is not normally included in language instruction, even for adults (Kim, et al., 1991). But some more subtle change might occur, so it is of interest to test for the effect in children closer to the age at which most of their language is being acquired.

A second limitation is that the results from Experiment 1, though showing that children use information other than phonology, does not show that the information they use is grammatical structure. Denominal verbs, by their very nature, are extended in meaning; their meanings are based on the meanings of the nouns that they are derived from. An alternative explanation for the results of Experiment 1 is that children, for some reason, have a tendency to regularize verbs that they think are semantically 'strange' or extended, which would include all of the denominal verbs, but none of the verb roots. This interpretation is similar to a proposal made by Lakoff (1987) for adults. Lakoff suggested that if a verb has an irregular past tense form among its range of meanings, it must have an irregular past tense form in its central sense. That is, no verb will have an irregular past tense form if a more central meaning for that verb has a regular past tense form. This generally accords with the fact that denominal verbs have

regular past tense forms and have relatively extended meanings, and that when a cluster of meanings of a verb has an irregular past tense form somewhere among its meanings, the most central sense is (usually) irregular. (However, Kim, et al., 1991, note several counterexamples in which the central sense of a verb is regular and its extended sense is irregular, such as *He wetted the washcloth* versus *The baby wet his diapers*.) Logically speaking, Lakoff's proposal that it is always the central senses that have irregular past tenses is consistent with the results of Experiment 1. But it would also be consistent with a finding of no difference, because the proposal makes no predictions for the extended senses of verbs which have irregular central senses; the past tense forms of such verbs' extended senses could be either regular or irregular, according to the literal content of the proposal. Therefore we will test a slightly stronger version of the hypothesis: If a verb is irregular in its central sense, it is likely to be regular in its extended senses.

Experiment 2, then, is similar to Experiment 1, except that it tests preschool children, and presents verb roots that, like their denominal counterparts, have extended meanings.

Method

Subjects. Twenty-six children ranging in age from 3;2 to 5;2 (mean 4;3) were drawn from daycare centers.

Materials, Design and Procedure. The design, procedure, and denominal materials from Experiment 1 were used. The verb root items were modified so that they were extended in meaning, as in (15). Appendix B presents the full list of extended verb root items.

(15) *Verb root:* Mickey likes to drive really fast. Look, Mickey is going to fly down the road. Can you say 'Mickey is going to fly down the road?' <have Mickey drive fast down the road> Mickey just __.

Six children participated in each of two of the versions, and seven participated in each of the other two versions.

Results

The data, which are summarized in Table 2, were analyzed as in Experiment 1. There was a significant main effect of morphological structure in a two-way ANOVA (4 Orders x Denominal/Verb Root) with Subjects as the random variable ($F(1,22) = 56.10, p < .001$), and in a one-way ANOVA with Items as the random variable ($F(1,8) = 15.62, p < .01$). For 21 of the 26 children, the proportion of regular and irregular responses which was regular was greater for the denominal items than for the verb root items; the other 5 subjects gave no irregular responses and so showed no difference between denominal and verb roots. For 8 of the 9 pairs of items, the proportion of the regular and irregular responses which was regular was greater for the denominal item than for the extended verb-root item; children never gave an irregular past tense form for the other item, *buy/bye*, and thus this item showed no difference between its denominal and verb root forms in proportion of regular responses (i.e. both were 100% regular).

Insert table 2 about here

Discussion

This study shows that three- to five-year-old children are more likely to produce regular past tense forms for denominal verbs than for homophonous verb roots, even if those verb roots are semantically extended. These results are consistent with the hypothesis that children's inflectional systems are sensitive to morphological structure and that they distinguish between irregular inflected forms (which are inherently bound to verb roots in memory and inherited via heads of endocentric structures), and regular forms (which are available by default). This finding replicates the results of Experiment 1 while addressing two alternative explanations. Nothing specific to schooling could have induced these results because the current subjects are preschoolers, and the extendedness of meaning for denominal items is eliminated as the factor causing the effect because here the verb roots were extended in meaning as well.

One noticeable difference between the results of this study and those from Experiment 1 is that children gave more regular responses for the extended senses of the

verb roots in the present experiment (46.6%) than the central senses of the verb roots in Experiment 1 (11.1%). Though this at first glance appears to show that extendedness itself affects regularization, there is a confound in the comparison between Experiment 1 and its replication here that prevents such a conclusion. The verb roots were extended in Experiment 2, but Experiment 2 also tested younger children (3;2-5;2, versus 6;8-8;10). Previous elicitation experiments show that the age difference itself is sufficient to account for the difference in the rates of overregularization. Kuczaj (1978) found that three- to four-year-olds overregularized 29% of the time, five- to six-year olds 49% of the time, and seven- to eight-year olds 1% of the time. Marchman (1988) found that four-year-olds overregularized 32% of the time, five-year-olds 33%, six-year-olds 22%, seven-year-olds 10%, and nine-year-olds 5% (see Marcus, et al., 1992, for a review). Our 47% versus 11% difference fits into this range easily, even if semantic extendedness plays no role. (We will also see in Experiments 3 and 4 that younger children overregularize more often in elicitation experiments than older children do, even when the methodology is held constant.) An across-the-board tendency for younger children to overregularize more could also explain their lower percentage of irregular responses to denominal verbs in this experiment (5.6%) than the percentage seen in their older counterparts in Experiment 1 (17.6%).

Experiment Three

Just as the phonology-only theory predicts that verbs which are homophonous with irregular past tense verbs will have irregular past tense forms, it predicts that nouns which are homophonous with nouns with irregular plural forms will have irregular plural forms. The grammatical structure theory predicts that only nouns with nouns roots in head position can have an irregular plural form: Exocentric nouns will tend to have a regular plural form, even if they are ultimately related to a noun root with an irregular plural form. This experiment tested these predictions with 7- to 10-year-old children.

Method

Subjects. Twelve children ranging in age from 7;1 to 9;6 (mean 8;8) were drawn from after-school programs.

Materials, Design and Procedure. The design of this experiment parallels the design of Experiment 1. Endocentric/exocentric pairs were constructed for irregular nouns. Six of the exocentric nouns were based on proper names that were in turn based on irregular nouns: *Batman, Wonder Woman, Mickey Mouse, Mother Goose, Superchild, Mr. Tooth* (a large tooth-like figure with a face on it). The other 3 were bahuvrihi compounds: *brown bigfoot, pink snaggletooth* (a walrus-like animal with large teeth), *walkman* (the latter is a unique compound, semantically different from standard English bahuvrihi compounds in that its referent does not possess the referent of the rightmost morpheme; the compound is a pseudo-English collocation invented in Japan). The endocentric counterparts of the exocentric nouns were common nouns with prenominal adjective modifiers that were matched with exocentric items for number of syllables: *fat man, skinny woman, fuzzy mouse, little goose, little child, purple tooth, brown big foot, yellow shark tooth, tall man.*

The experimenters suggested the derivational status of the noun to the children by using the noun initially either as a name, a bahuvrihi compound, or a common noun, using the wording in (16)-(18), respectively.

(16) *Name*: This is Mr. Tooth. Can you say 'This is Mr. Tooth?' <bring out another Mr. Tooth figure> There are two __.

(17) *Bahuvrihi*: This is a pink snaggletooth. Can you say 'This is a pink snaggletooth?' <bring out another snaggletooth figure> There are two __.

(18) *Noun*: This tooth is red. But this is a purple tooth. Can you say 'This is a purple tooth?' <point to another purple tooth> There are two __.

Results

The data, which are presented in Table 3, were analyzed as in the previous experiments. There was a significant main effect of Grammatical Structure (endocentric/exocentric) in a two-way ANOVA (4 Orders x Exocentric/Endocentric) with Subjects as the random variable ($F(1,8) = 13.08$, $p < .01$), and in a one-way ANOVA with Items as the random variable ($F(1,8) = 18.08$, $p < .01$). For 9 of the 12 subjects, the proportion of regular and irregular responses which was regular was greater for exocentric items than for endocentric items; one subject gave a greater proportion of regular responses in the endocentric condition than in the exocentric condition; the other

2 subjects gave no regular responses at all and so showed no difference between endocentric and exocentric conditions in the proportion of regular responses. For 8 of the 9 pairs of items, the proportion of the regular and irregular responses which was regular was greater for the exocentric item than for the endocentric item; one item, *skinny woman/Wonder Woman,* had a greater proportion of regular responses for the endocentric item than the exocentric item. The tendency to regularize was approximately the same for the 3 bahuvrihi nouns and the 6 nouns derived from names (27.8% and 24.6% of responses, respectively, excluding no-change and uncodable responses).

Insert table 3 about here

Discussion

Children gave more regular plural responses for exocentric nouns than for endocentric nouns. This extends the evidence that children's inflection is sensitive to morphological structure, and not just phonological composition. Children are sensitive to the derivation of nouns as well the derivation of verbs. They are sensitive not only to a change of grammatical category, as in the previous experiments, but to other forms of exocentrism, such as whether a nominal merely contains an irregular noun, or has the irregular noun as its head. Moreover they showed this sensitivity to the same degree when the exocentric noun referred to the same object as its root (nouns derived from names, like *Batman*) and when it referred to only a part of that object or a different object (bahuvrihi nouns, like *Snaggletooth* or *walkman*). This suggests that the children did not use some simple semantic criterion for regularization but were sensitive to exocentrism itself.

Though the rate of irregular responses for exocentric nouns was lower than for endocentric nouns (69.4% versus 93.5%), it was fairly high, and much higher than for exocentric verbs in Experiment 1 (17.6%). The reasons for this are unclear. Perhaps it is because the stories which were used to present the different nouns in this study were nearly identical to one another, whereas the stories from Experiments 1 and 2 varied. As a result, the children may not have paid as much attention to the context defining the

items as exocentric. Another possibility is that if speakers should ever misanalyze exocentric items as endocentric (say, if they analyze *to fly out* as a metaphorical form of flying rather than one result of hitting a fly ball, or *Batman* as a kind of man rather than a name for a man) they should keep its inflected form irregular. Kim, et al. (1991) were able to obtain independent measures of the likelihood of such reanalyses, and confirmed that they diluted the regularization of exocentric verbs. But such reanalyses are even more natural for exocentric nouns, because their rightmost noun morphemes can be interpreted as picking out some multiplicity of objects just when the exocentric nouns pick out some multiplicity of objects. That is, *two Batmans* are also two men, *pink snaggletooths* have many teeth, and so forth. So even though we designed the experiment so that children had to use the name items with the syntax appropriate for names, misanalyses may have been tempting, and they would have diluted the effects (fortunately, not completely).

Experiment Four

The goal of this experiment is to replicate Experiment 3 with preschool children. In a pilot study using the same methodology as in Experiment 3, we found that preschoolers virtually never responded with irregular plural forms in either the exocentric or endocentric conditions. As noted, this is consistent with the findings summarized by Marcus, et al. (1992) that younger children overregularize more than older children do, and that experimental elicitations, in particular, exaggerate the tendency to overregularize, by an order of magnitude or greater. (It also confirms that age is sufficient to account for the difference in regularization rates in Experiments 1 and 2.) To get our dependent variable of regularization rate off the ceiling for preschoolers, we had to modify the procedure to bias them to give irregular responses. Of course, this bias was introduced across the board, for both endocentric and exocentric items, so it does not confound the results obtained.

Method

Subjects. Twenty children ranging in age from 3;5 to 5;0 (mean 4;2) were drawn from daycare centers.

Materials, Design and Procedure. The design and materials from Experiment 3 were used. The only difference is that we asked the children to repeat the irregular plural form of a noun, with no context, just before presenting the relevant experimental item to them, a manipulation that biases the children towards giving irregular plural forms, both for endocentric and exocentric items. Five children were run in each of two orders, four children were in another order, and six children were in the last order.

Results

The data are presented in Table 4; they were analyzed as in the previous experiments. There was a significant main effect of morphological structure (Exocentric versus Endocentric) in a two-way ANOVA (4 Orders x Exocentric/Endocentric) with Subjects as the random variable ($F(1,16) = 13.28$, $p < .05$), and in a one-way ANOVA with Items as the random variable ($F(1,8) = 17.50$, $p < .01$). For 14 of the 20 children, the proportion of regular and irregular responses which was regular was greater for the exocentric item than for the endocentric item; 2 children gave a greater proportion of regular responses in the endocentric condition than in the exocentric condition; 4 children showed no difference. Of the 4 children that showed no difference, one gave no regular responses, and 2 gave no irregular responses. All 9 pairs of items had a higher proportion of regular responses for exocentric items than for endocentric items. The tendency to regularize was slightly smaller for the 3 bahuvrihi nouns than for the 6 nouns derived from names (65.8% and 77.8% of responses, respectively, excluding no-change and uncodable responses). This shows that children's tendency to regularize was not exclusively a response to nouns whose referents differed from those of their roots.

Insert table 4 about here

Discussion

The children in this experiment gave a higher proportion of regular plural responses for exocentric nouns than for endocentric nouns. This provides further evidence that preschool children are not just sensitive to phonology in figuring out how to inflect

words, but to grammatical structure as it reflects the relation between a complex word and its root.

General Discussion

In the experiments reported in this paper, children were more likely to regularize denominal verbs than homophonous irregular verb roots; similarly, they were more likely to regularize exocentric nouns than homophonous irregular endocentric nouns. These results show that the input to children's inflectional systems cannot just be the phonological representations of words, as it is in the models of Rumelhart & McClelland (1986), Plunkett & Marchman (1990, 1991), Seidenberg & Daugherty (1992), and Hare & Elman (1992). Moreover, the effect cannot be due to children avoiding irregulars whenever a verb form has an unexpected meaning.

The studies reported in this paper are consistent with the hypothesis that children at an early age are sensitive to the abstract linguistic notions that underlie the linguistic knowledge of adults. It is important to note that no special theory has to be constructed to account for the phenomenon of regularization by exocentrism (for either children or adults). It falls out of the nature of irregularity and the scheme by which complex words are interpreted from the arrangement of their parts -- that is, how speakers know that *breadbox* is a kind of box, not a kind of bread, and that *to brake* means to apply brakes (Lieber, 1980; Williams, 1981; Selkirk, 1982; Pinker & Prince, 1988; Spencer, 1990; Kim, et al., 1991; Pinker & Prince, 1991). The principles are that (i) irregularity is a link between two word roots -- a stem form and its irregularly inflected form; (ii) derived words are decomposed into abstract morphological structures reflecting their derivation from more basic morphemes, (iii) lexical features (including, but not restricted to, irregularity) are passed up to a whole word only through head positions, hence words that are headless cannot inherit grammatical features of the morphemes they are constructed out of, and (iv) regular past tense inflection applies by default whenever it is not specifically blocked by irregularity.

Alternative Accounts

Degree of Semantic Extendedness

Recall that Lakoff aimed to explain regularization of denominal verbs by semantic extendedness: if a polysemous verb has an irregular past tense, its central sense will be irregular. This hypothesis, however, fails to predict any difference; it simply predicts no difference in the opposite direction. Moreover, the hypothesis that extendedness but not exocentrism causes regularization is refuted by the greater degree of regularization found for exocentric items in Experiment 2, where verb root items as well as denominal verb items were extended in meaning. But there is another conceivable hypothesis: Extendedness comes in degrees, and denominal verbs are more extended in meaning than extended verbs with verb roots. If so, semantic extendedness might suggest an alternative explanation for the data: If extended verbs are more likely to be regularized, and if the denominal verbs are more extended than the verb roots, denominal verbs should be regularized more often.

This explanation cannot be completely ruled out in this set of studies. However, Kim, et al. (1991) did several statistical analyses unconfounding semantic extendedness and exocentrism, and showed that for adults, only the latter could unambiguously account for their judgments. Using a dummy variable for denominal versus verb-root structure, and a set of independent ratings of semantic extendedness, Kim, et al. (1991) found that the unconfounded effects of exocentrism accounted for a significant 22.8% of the variance in subjects' preference for regular forms, but the unconfounded effects of semantic extendedness accounted for only 0.6% of the variance (the rest of the variance was jointly accounted for, or not accounted for by either variable). Second, the effect of semantic extendedness was entirely localized to denominal verbs, which is unexplained if there is no qualitative difference between denominal and deverbal verbs aside from semantic extendedness. Together with other findings, this led Kim, et al. to conclude that the only effect of semantic extendedness is to make it more likely that subjects mis-analyzed denominals as being headed by an irregular verb root. Since the grammatical structure theory is consistent with data from adults and children, it offers the simplest account for all the data; if the grammatical structure theory were true for adults but the semantic extendedness hypothesis were true for children, an additional theory has to be developed that explains how children's knowledge is qualitatively reorganized

when children become adults.

Reducing Ambiguity

Harris (1992) suggests that speakers give regular past tense forms for denominal verbs which are homophonous with irregular verbs because doing so keeps denominal and deverbal verbs phonologically distinct. That is, some process calculates that it serves effective communication to assign a denominal verb a past tense form which is distinct from the past tense form of a homophonous deverbal verb (e.g. *I spitted/*spat a pig for the pig roast* versus *I spat/*spitted on the ground in disgust*). This can be done because there exists a linguistic device that can signal such a distinction: the productive *-ed* past tense suffix.

The ambiguity-reduction account has some preliminary intuitive appeal because inflected exocentric forms happen to differ both in form and meaning from their homophonous endocentric irregular counterparts. But further examination shows that the ambiguity-reduction hypothesis is incorrect:

1. Ambiguity-reduction should call for regularization whenever there is a significant meaning change in a novel verb form, not only when there is a meaning change secondary to exocentrism. But as noted at the end of the Introduction, and by Pinker & Prince (1988) and Kim, et al. (1991), endocentric forms with irregular heads do not regularize. Pinker & Prince (1988) note: 'Verbs like *come, go, do, have, set, get, put, stand* ... are magnificently polysemous (and become more so in combination with particles like *in, out, up, off*), yet they march in lockstep through the same nonregular paradigms in central and extended senses -- regardless of how strained or opaque the metaphor.' (pp. 112-113) The recently-popularized idiom *blow him away*, ambiguously meaning either 'overwhelm' or 'execute' but with past and participle *blew/blown*, never *blowed*, is just one out of literally hundreds of examples. Kim, et al. (1991) also showed quantitatively that people's ratings of semantic extendedness had an unconfounded correlation of zero with their tendency to regularize verb roots (though the ratings of semantic extendedness had a small correlation with the tendency to regularize denominal verbs, reflecting subjects' tendency to misanalyze such verbs as endocentric).

2. Most exocentric forms are not even ambiguous. Harris's theory derives from the tenets of 'functional grammar,' according to which 'speakers choice of one linguistic

form over another is influenced by perceived communicative gain. ... A salient task in judging novel verbs phonologically related to irregular verbs is guarding against miscommunication' (Harris, 1992, from the Abstract). Therefore her account should predict that regularization would only be a tempting option when the morphological, semantic, and syntactic context leaves the sense of a derived verb ambiguous, not when this context makes the meaning completely clear, so that the 'perceived communicative gain' is nil and 'miscommunication' impossible. But for the vast majority of denominal verbs, the meaning of the related verb root would be either ungrammatical, given their prefixes and arguments, or absurd in context. For instance, of the 18 denominals given in (2), only 4 (*brake, cast, out-do, string*) could conceivably be ambiguous in the contexts provided. Surely no speaker entertains the possibility that one can expectorate a pig (2c), levitate oneself into center field (2b), or tap a city causing it to resonate (2d). But the denominal verbs all regularize, and apparently to the same degree.

3. Ambiguity reduction does not predict that denominal verbs should always have a *regular* past tense form; it only predicts that they should have a *different* past tense form than their homophonous verb roots, whenever phonologically possible. Recall that irregular patterns like *ing-ang-ung* and *eel-elt*, though less productive than the regular suffix, can be applied to new words if they are phonologically similar to existing irregulars, like *spling* or *cleed* (Bybee & Moder, 1983; Kim, et al., 1991; Prasada & Pinker, 1993). Therefore under the ambiguity-reduction account they, too, should be available to disambiguate derived forms. In particular, denominal verbs that are homophonous to existing *regular* verbs and that are phonologically similar to clusters of irregulars supporting semiproductive irregular patterns should have irregular past tense forms under this account. But no such tendency exists. For instance, though the verb *to heal* in (19a) has a regular past tense form, the denominal verb *to heel* in (19b) also has a regular past tense even though it could have been given the ambiguity-reducing past tense form *helt* by analogy to the *kneel/knelt, feel/felt* cluster of irregular past tense verbs.

(19) a. My broken arm *healed/*helt* quite nicely.

b. I hate it when my sister stomps on my foot with her heel.
She *heeled/*helt* me so hard yesterday that she broke my foot.

(20) a. I nearly *keeled/*kelt* over after running the race.

b. I usually install the keels on the boats our company produces.
But yesterday Sue *keeled/*kelt* the boats instead.

(21) a. I *stared/*store* at him for hours.
b. For exercise, I used to bike but now it's so cold that I run stairs.
Yesterday, I *staired/*store* for an hour.

Preference for the regular inflected form even in the face of homophony can be seen in many other examples, including ones where there are two distinct denominal senses, one established, the other novel:

(22) a. I bought a new hoe for the garden in my backyard.
The day I bought it, I *hoed/*hew* in the garden for hours.
b. Steve used to yell 'ho' at me for no apparent reason.
He *ho'd/*hew* me one too many times, so I blew up.

(23) a. Lancelot worked hard to become a knight.
The king finally *knighted/*knit/*knought* him today.
b. I decided that my painting should depict the night rather than the day.
So I bought some dark paints and *nighted/*nit/*nought* the painting.

Though some of these examples are strained, there is not even a hint of a tendency toward irregularization, not even if we stack the deck in favor of it. One such bias is to look for cases where there is the possibility of a regular *or* an irregular form, both of which are distinct from the form of the homophonous root. For instance, though *to fling* in (24a) has the irregular past tense form *flung*, the denominal verb *to out-fling* in (24b) has no tendency to have the past tense form *out-flang* by analogy to the *ring/rang, stink/stank* cluster of irregular past tense verbs, even though this is not prevented on grounds of communicative efficacy (i.e. *flang* is phonologically different from *flung*).

(24) a. Janet *flung/*flinged/*flang* her clothes all over the place.
b. Janet was fed up with her husband Sam's recurring flings with waitresses.
So she had more flings than Sam; she *out-flinged/*out-flang* him.

(25) a. Boggs *swung/*swinged/*swang* and missed.

b. I have to put the swing on the tree every March.

This year I was lazy and *swinged/*swang* the tree in April.

Note in particular that denominal verbs ending in *-ing* should be particularly liable to being irregularized if ambiguity-reduction were a factor, because the *ing/-ang* and *-ing/-ung* irregular clusters are quite distinctly irregular: There are no regular monosyllabic verb roots ending in *-ing* (Pinker & Prince, 1988). Nonetheless, denominals go regular, even when they are particularly close to the *ing-ang-ung* cluster of irregular verbs.

4. Denominal verbs reliably take regular inflection even when there is no existing irregular that could be a source of ambiguity. For example, the very strong *ing-ang-ung* pattern is not applied to the following non-homophonous denominal verbs:

(26) a. She *kinged/*kang/*kung* the checker piece.

b. My car *pinged/*pang/*pung* all the way home.

c. My mother *dinged/*dang/*dung* the side of my car again.

d. I forgot my slides and *winged/*wang/*wung* it.

Similarly, in the final experiment of Kim, et al. (1991) subjects preferred a regular past tense form to an irregular past tense form more strongly for denominal verbs than for homophonous verb roots when all the verbs to be inflected were novel (each novel verb was phonologically similar to a cluster of irregulars like *to spling*, and subjects frequently did extend the *ing-ang-ung* pattern to the novel forms).

In sum, contrary to Harris (1992), denominalization reliably causes regularization, whether or not some ambiguity is eliminated, and ambiguity does not cause

regularization, unless it is accompanied by denominalization.[14] Note that we are not suggesting that regularization of exocentric forms is an arbitrary quirk, unrelated to the functions of grammar. Grammatical structure, and inheritance of grammatical features through heads, plays a crucial role in how people coin and interpret complex new words, and a default regular rule is surely useful. It's just that the phenomenon of regularization of exocentric forms is a by-product of the mechanics of this system; it is not something that speakers strive for (deliberately or not) with some immediate communicative goal in mind. (Indeed, it is of dubious functional value for people to go to such trouble in disambiguating only the *past tense* and *plural* forms of such verbs, while tolerating the ambiguity in the far more frequently used present, progressive, infinitival, and singular forms.)

Semantic Features

Since verbs have meanings as well as sounds, it might seem natural to feed a verb's semantic representation into the stem-to-past tense mapping mechanism, together with its phonological representation. That would suffice in principle to distinguish between homophonous verbs with different past tense forms. This straightforward augmentation of the Rumelhart-McClelland model was implemented by MacWhinney & Leinbach (1991) in a 'small auxiliary simulation.' Units which represent parts of the meanings of words were added to the bank of input units, supplementing the phonological input units. This allowed the model to distinguish 3 homophones, among a set of 10 verbs, after 2400 epochs of training.

As mentioned in the Introduction, adding semantic features to a distributed representation has the effect of defining semantic subtypes of verbs that one would

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[14]Harris (1992) presents some regression analyses designed to show that semantic relatedness of a novel form and an existing irregular predicts regularization better than grammatical structure does. But her data are uninterpretable for several reasons: (1) She analyzed ratings of regular and irregular forms separately, rather than the difference between them, as in Kim, et al. (1991), so her two regression analyses reflect subjects' reactions to the overall felicity and plausibility of the derived verb meanings, rather than their relative preference for regular or irregular inflected forms. (2) She included an unexplained predictor variable ('homonym/polyseme') in the regression that was confounded with grammatical structure but that had no motivation within her theory. Indeed, her theory made two predictions, one in her Hypothesis, the other in her Conclusion, that are incompatible with the effects of that variable. (3) She did not do the crucial test, as performed in Kim, et al. (1991), to determine whether semantic relatedness predicted regularization among the verb roots alone, the prediction that is most clearly independent of the grammatical structure hypothesis.

expect to have similar past tense forms, just as overlap in phonological features defines clusters of verbs with similar past tense forms -- but this prediction, in the case of semantic features, is not true. For instance, though *slap*, *hit* and *strike* have similar meanings, they have different past tense forms -- *slap* has the regular past tense form *slapped*, *hit* has the no-change past tense form *hit*, and *strike* has the stem-changing past tense form *struck*. Conversely, though *sting*, *sing*, *swing*, and so forth form their past tenses in similar ways, they do not comprise a semantically coherent set of verbs. This is true not just of these examples, but throughout the verb lexicon. And as mentioned, if several words are sensed as having the same verb morpheme as their head, they will all have the same past tense form, no matter how semantically dissimilar they are, as in the idioms containing *take, put, give, make, have, come, go*, and *set*. Moreover inheritance of irregularity occurs not only when the verbs are used in isolation and when they are combined with particles, but even when they are combined with prefixes whose contribution to semantic composition is weak or non-existent such as *be-*, *for-*, *under-*, and *over-* as in *undertook/*undertaked, became/*becomed, overcame/*overcomed, forgot/*forgetted*, and *understood/*understanded*.

It is also worth noting that MacWhinney & Leinbach's addition of semantic feature nodes to their past tense network amounts to a theoretically odd claim. Unlike their phonological representation, the semantic representation is not claimed to be adequate to represent the verbs' meanings. (Indeed, a rich enough set of meaning nodes, combined with reasonably-sized hidden layers of nodes, might encourage the net to develop 'grandmother cells' for the meanings of particular words, preventing desirable generalization to new, similar-sounding words altogether.) The particular semantic nodes that were used in the model were simply chosen because they were sufficient to disambiguate the homophones in MacWhinney & Leinbach's training set of 10 verbs. Furthermore, 15 of their 25 semantic features appeared only in the representation of one word in their simulation: 9 of these were assigned to *wring* (a washcloth), *ring* (a bell), *ring* (a city) (an average of three semantic features each), whereas only 6 were assigned to the 7 non-homophones (an average of less than one semantic feature each). But why should homophones be given more unique semantic features than non-homophones? Clearly this was an ad hoc response to the past tense homophone problem pointed out by Pinker & Prince (1988). In actuality, the 'features' that distinguish (say) *wring* from *ring*

are their distinct identities as lexical items, not any particular subset of semantic features.

More generally, it is not clear what set of 'semantic features' would ever distinguish endocentric from exocentric items. A node for the feature 'exocentric' would work mechanically, of course, but would be ad hoc to the problem. It would not explain why words with that 'feature' are, in particular, verbs that are derived from nouns, bahuvrihi compounds, nouns derived from names, and the other circumstances that define 'exocentrism.' The point of the grammatical structure theory is that all exocentric words regularize *for the exact same reason* -- verbs from nouns, nouns from verbs, nouns from names, nouns from verb phrases, quoted nouns, words that stand in a 'has' rather than 'is' relation to their roots, and foreign compounds like *walkman* are all represented as exocentric, and for reasons independent of their tendency to regularize (see also Marcus, et al., 1993).

Aside from exocentrism per se (which goes into the scheme for determining meaning, but is not a feature of meaning itself), there is no property that exocentric items have in common semantically and that differentiates them from related endocentric items. Denominal verbs are semantically heterogeneous (Clark & Clark, 1979), as are bahuvrihi compounds and nouns-from-names. Conversely, verbs derived from nouns which are, in turn, derived from irregular verbs (i.e. V->N->V) clearly share semantic features with the irregular verb roots out of which they are built, but are regularized despite this similarity (because they are exocentric). These include not only general semantic features like 'cause' or 'punctate action' or 'animate,' but specific features shared with their particular root counterparts, as in *flied out* and *costed out.* (That is, *fly out* shares features like 'involves motion through the air' with the verb root *fly.*) The same is true for bahuvrihi compounds like *bigfoots*, *flatfoots*, and *saber-tooths*, and many nouns from names like *Mickey Mouses* and *snaggletooths.* For example, *saber-tooth* shares features like 'has sharp hard white point' with *tooth*, and *Mickey-Mouse* shares features like 'rodent' with *mouse.* The necessary 'features' in fact would have to involve abstract relational notions like '*is* versus *has* the referent of the root word,' and not the binary present/absent properties that could reasonably be treated as primitive semantic features. It is hard to see how these semantic properties could be modeled without duplicating the kinds of morphological structure and feature-percolation-through-heads that are posited by linguistic theory. Such postulates, together with the claim that irregularity involves

stored roots and regularity a default rule, yield regularization of all the different kinds of exocentric forms at once, without special wiring for each one.

Learnability Issues

It is not easy to see how children could learn these principles, and there is some reason to believe that they may not. That is, there may not be enough information in children's linguistic environment for them to learn that stems have an irregular inflected form only if they are headed by an irregular root, and that exocentric stems have regular inflection across the board. Marcus, et al. (1992) showed that children hear denominal verbs that are not homophonous with irregulars, like *fish, plug, rain, rope*, and *screw* (and probably hear at least some of them in the past tense). But this does not tell children what to do in the relatively rare conflict circumstances where a verb has a phonological representation associated with an irregular past tense form but has a grammatical structure that prevents such information from being passed upward to the word as a whole; that is, for denominals that are homophonous with irregulars. In such cases, children might simply use the verb's phonological representation and produce an irregular past tense form. The experiments reported in this paper refute this possibility. In order for children to learn that denominal verbs are always regular, they would have to hear the regular past tense forms of denominal verbs which are homophonous with irregular past tense verbs. But in a search of the transcripts of Adam, Eve, Sarah, and Abe in the ChildES database (MacWhinney & Snow, 1985; MacWhinney, 1990), we found no denominal verbs which are homophonous with irregular verbs in 7500 parental utterances. If this type of linguistic input is not available to children, then some endogenous mechanism must be responsible for driving them to regularize denominal verbs. The simplest account is that children's linguistic systems are inherently organized to distinguish rules from lexical storage (with regular and irregular inflection associated with these two modes of producing linguistic forms, respectively), and to use head inheritance to interpret new complex words from their familiar components. The regularization of exocentric stems, a predictable outcome in a rare circumstance, is an automatic consequence of this basic design.

Gordon (1985), using different methods and constructions, reached a similar conclusion. He conducted an experiment showing that children produce compounds that contain irregular plurals (e.g. *mice-eater*), but they never produce compounds that

contain regular plurals (e.g. *rats-eater*). He discovered a fact that led him to claim that children are innately disposed to allow irregular plurals but not regular plurals inside compounds: The frequency of compounds with plurals (of any kind) as their first element is vanishingly rare in standard frequency counts (Kucera & Francis, 1967). Because children hear neither type of plural inside compounds from their parents, they could not have learned the fact that only irregular plurals can be in nonhead positions of compounds. Gordon (1985) concludes that children's lawful behavior when confronted with such a rare linguistic circumstance reflects the basic design of morphology: Irregulars (as simple words, presumably tied to the lexicon) can enter into the compounding rule, a derivational process that takes lexical stems as its input; regulars are the product of an inflectional rule that applies after morphological derivation (such as compounding) with the result that the product of the regular inflectional rule cannot enter into the compounding process. Again, there is no innate knowledge specific to the behavior of irregular and regular forms in compounds; the interaction automatically falls out of the basic organization of the morphological system, with regular inflection as a default process applying at the end of a derivation.

Conclusion

The studies reported in this paper support the simple hypothesis that children are like adults, only noisier. They probably represent whether verbs (and nouns) are headed by roots using the same kinds of structured representations that adults do. Moreover they appear to distinguish irregulars (as forms that must be passed on from the lexicon) from regulars (which can be generated as a default operation). The information necessary to learn the discriminations children make is absent from parental speech, suggesting that the discriminations reflect the inherent organization of children's linguistic systems. Such conclusions, if borne out by subsequent research, have consequences for other phenomena in language acquisition. For example, insofar as the phenomena discussed in this paper implicate qualitatively different mechanisms for regular and irregular inflection, the use of such a distinction to explain overregularizations like *comed* and their U-shaped developmental pattern receive independent support (see Marcus, et al., 1992).

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APPENDIX A. EXPERIMENTAL ITEMS FROM EXPERIMENT ONE

A.1 Denominal Items

1. *'C'*: This is an 'A'. I'm going to 'A' you. <give the letter 'A' to the child> Now, this is a 'C'. Now I'm going to 'C' you. <give the letter 'C' to the child> I just ____.

2. *bye*: Kermit likes to say 'hi' and he likes to say 'bye.' Now, Kermit is saying 'hi' to you. <have Kermit say 'hi' to the child> Kermit likes to 'bye' even more. <have Kermit say 'bye' to the child> Now Kermit is going to 'bye' you. Kermit just ____.

3. *meat*: This is a bun. This is meat and this is cheese. First, I'm going to cheese the buns. <put cheese on the bun> Now I'm going to meat the buns. <put meat on the bun> I just ____.

4. *drink*: This is a drink. Can you say 'This is a drink?' First, I'm going to french fry you. <give french fries to the child> Now I'm going to drink you. <give drink to the child> I just ____.

5. *fly*: This is a fly. Can you say 'This is a fly?' I'm going to fly this board. <put flies all over the board> I just ____.

6. *stick*: This is a stick. Can you say 'This is a stick?' I'm going to stick the cup. <hit the cup with the stick> I just ____.

7. *right*: Mickey likes to drive in his car. Mickey likes to go this way. <have Mickey go left> See, Mickey likes to left in his car. Can you say 'Mickey likes to left?' Mickey also likes to go this way. <have Mickey go right> See, Mickey likes to right in his car. Can you say 'Mickey likes to right?' <have Mickey go right again> Mickey just ____.

8. *leave*: These are leaves. Can you say 'These are leaves?' I like to leave the table. <cover the table with leaves> I just ____.

9. *ring*: This is a ring. Can you say, 'This is a ring?' I am going to ring your finger. <put the ring on the child's finger> I just ____.

A.2 Deverbal Items

1. *see*: I like to see with this telescope. Can you say 'I like to see with this telescope?' I'm going to see you through the telescope. <look through the telescope at the child> I just ____.

2. *buy*: <give the child a bell and a ring> Kermit likes to buy things with money. First, Kermit is going to buy a bell from you. <have Kermit trade money for a bell> Now Kermit is going to buy a ring from you. <have Kermit trade money for the ring> Kermit just ____.

3. *meet*: Mickey likes to meet people. Can you say 'Mickey likes to meet people?' He's going to meet Wonder Woman. <have Mickey meet Wonder Woman> Now Mickey'll meet Batman. <have Mickey meet Batman> Mickey just _____.

4. *drink*: Kermit likes to drink. Can you say 'Kermit likes to drink?' Kermit is going to fill his cup with water. <have Kermit fill the cup with water> Now Kermit is going to drink it. <have puppet pretent to drink from a cup> Kermit just ____.

5. *fly*: This airplane is going to fly. Can you say 'This airplane is going to fly?' The airplane is about to fly through the air. <have the airplane fly about> The airplane just ____.

6. *stick*: This putty sticks to things. Can you say 'This putty sticks to things?' I'm going to stick this putty on the ball. <stick putty on the ball> I just ____.

7. *write*: Kermit likes to write on the board. Can you say 'Kermit likes to write on the board?' First, Kermit is going to write 'yes'. <have Kermit write 'yes'> Now, Kermit is going to write 'no'. <have Kermit write 'no'>

Kermit just ____.

8. *leave*: Kermit wants to leave. Can you say 'Kermit wants to leave?' Kermit is going to leave the table. <have kermit leave the table> Kermit just ____.

9. *ring*: I like to ring this bell. Can you say 'I like to ring this bell?' I am going to ring this bell. <ring the bell> I just ____.

APPENDIX B. EXTENDED DEVERBAL ITEMS FROM EXPERIMENT TWO

1. *see*: <blindfold a doll and have the doll touch a bracelet> This doll is going to see the bracelet. Can you say that? Now, this doll is going to see the sponge. <have the doll touch the sponge> Now tell Mother Goose. This doll just ____.

2. *unbuy*: <give the child rings> I am going to buy that ring. <give money to the child and take the specified ring> Do you know what? I don't like this ring. I am going to unbuy the ring. Now tell Mother Goose. I just ____.

3. *meet*: See this pen? This pen is going to meet the table. Can you say that? <touch the pen to the table> Now tell Mother Goose. This pen just ____.

4. *drink*: I am really thirsty. I am so thirsty I am going to drink the air. Can you say that? <inhale air as if drinking> Now tell Mother Goose. I just ____.

5. *fly*: See Mickey? Mickey is going fast. Mickey is going to fly down the road. Can you say 'Mickey is going to fly down the road?' <have Mickey drive fast down the road> Now tell Mother Goose. Mickey just ____.

6. *stick*: See the silly putty? Watch. I am going to stick the comic strip on the silly putty. Can you say that? <press silly putty against the comic strip, making an imprint on the silly putty> Now tell Mother Goose. I just ____.

7. *write*: Watch. I am going to write your name. <arrange lettered cards so

they spell the child's name> Can you say that? Now tell Mother Goose. I just ____.

8. *unleave*: Superman is really busy. He's going to leave the room. <have Superman leave> Oops. Superman forgot something. He better unleave the room! <have Superman return> Now tell Mother Goose. Superman just ____.

9. *ring*: See this stick? I am going to ring this stick against the floor. <bang the stick against the floor> Watch. See I'll do it again. <do it again> Now tell Mother Goose. I just ____.

Table 1

Children's Final Responses in Experiment 1

	Regular	Irregular	No Change	Uncodable
Denominal Verbs	66.7%	17.6%	11.1%	4.6%
Verb Roots	11.1%	87.0%	1.9%	0%

Table 2

Children's Final Responses in Experiment 2

	Regular	Irregular	No Change	Uncodable
Denominal Verbs	64.1%	5.6%	20.5%	9.8%
Verb Roots	46.6%	22.6%	23.5%	7.3%

Table 3

Children's Final Responses in Experiment 3

	Regular	Irregular	No Change	Uncodable
Exocentric Nouns	24.1%	69.4%	6.5%	0%
Endocentric Nouns	4.6%	93.5%	1.9%	0%

Table 4

Children's Final Responses in Experiment 4

	Regular	Irregular	No Change	Uncodable
Exocentric Nouns	50.0%	17.8%	24.4%	7.8%
Endocentric Nouns	43.9%	33.3%	18.9%	3.9%

CHAPTER 3

The Effect of Word Structure on the Online Computation of Inflection

Introduction

Despite the success that formal linguistic theories have had in elegantly accounting for a wide range of linguistic phenomena, many psychologists remain skeptical of the psychological reality of the abstract linguistic representations that linguists propose except in the most simple and straightforward of cases. For this reason, inflectional morphology has constituted a paradigm case of the rule-based nature of linguistic knowledge among psychologists since Berko's (1958) demonstration that children are productive with inflectional morphology. That is, because children are able to give, say, past tense forms for novel verbs which they could not have heard in their linguistic input by adding "-ed" to their stem forms, they must have a productive mechanism for inflecting verbs; the regular past tense rule, by which "-ed" is concatenated with a variable (i.e., a verb stem), has exactly this property.

But recent years have seen an alternative account for the productivity of inflectional morphology. Connectionist or Parallel Distributed Processing (PDP) models consist of networks of densely interconnected units whose connection strengths are adjusted during an extensive training schedule (Rumelhart & McClelland, 1986). Though these models are compatible in principle with abstract grammatical categories, structured representations, and multiple components, in practice PDP language modelers (e.g. Rumelhart & McClelland, 1986; Plunkett & Marchman, 1990, 1991; MacWhinney & Leinbach, 1991; Daugherty & Seidenberg, 1992; Hare & Elman, 1992) attempt to do away with such representations, preferring a single, homogeneous network that maps the features of an input word form to the features of an output word form. Thus, connectionist modelers have attempted to show that the architecture of the inflectional system is not inherently organized in such a way that it handles regular and irregular inflection with qualitatively different mechanisms, a qualitative difference that might be said to implement a regular inflectional rule as proposed in formal linguistic theories. The intuition underlying this practice among these PDP modelers is that the formal linguistic representations proposed by linguists are epiphenomenal and that the *true* explanation for linguistic phenomena lies elsewhere, possibly in homogeneous associative-style networks.

This paper has two purposes. The first is to show how morphological structure directs the online computation of regular past tense forms of verbs. It does this by

showing that though the time it takes subjects to produce the past tense form of a regular past tense verb root is affected by phonologically similar irregular past tense verbs, this difference disappears when the morphological structure of a verb preempts the possibility of its having an irregular past tense form. Thus, the studies in this paper provide data relevant to determining how the mechanism that computes regular past tense forms is affected by factors such as the phonological similarity of regular past tense verbs to irregular past tense verbs and the morphological structure of verbs. The second purpose of this paper is to show that the best account for these phenomena relies on separate inflectional mechanisms for computing regular and irregular past tense forms, in contrast to the homogeneous networks that PDP language modelers have proposed for past tense inflection.

The Productivity of Regular and Irregular Past Tense Formation

In addition to the rule-like productivity of regular past tense formation, there is a less well-known productive component of the past tense inflection system: The semi-productivity of irregular past tense verbs. That is, the irregular past tense verbs that pattern with other phonologically similar verbs form clusters which are the basis for phonological generalization (Bybee & Slobin, 1982; Bybee & Moder, 1983). Examples include irregular past tense verbs whose stem has an *i* followed by a velar nasal consonant, such as *sing/sang, ring/rang, spring/sprang, drink/drank, shrink/shrank, stink/stank*, and the closely related class *string/strung, sting/stung, swing/swung, sling/slung, wring/wrung*, and so on. Evidence that these clusters of irregular past tense verbs have a productive aspect include the following:

1. Historical evidence: *Catch/caught, cost/cost, fling/flung, kneel/knelt, quit/quit, sling/slung, stick/stuck*, and *string/strung* have been assimilated into irregular past tense clusters within the past several hundred years under the influence of phonologically similar existing clusters of irregular verbs (Jesperson, 1942/1961).

2. Dialectal evidence: Many dialects of English show that the subregularities must have been at least somewhat productive at some time. For example, *thunk* is a common past tense form for *think*, which presumably is due to the partial productivity of the *sting/stung* cluster.

3. Children's spontaneous productions: Children occasionally use forms like *brang* for *brought*, *bote* for *bit*, and *truck* for *tricked* (Xu & Pinker, 1992).

4. Experimental evidence: Bybee and Moder (1983) have shown that when experimental subjects are asked to produce the past tense form of a novel verb (e.g., *to spling*), the likelihood of an irregular past tense response (e.g., *splung*) increases with the phonological similarity of the novel verb to the phonological prototype of an irregular past tense cluster (see also Prasada & Pinker, 1993).

There is general agreement that phonological information must be used to compute past tense forms, but there is disagreement over how this information is used. Some linguists have proposed that the redundancy and partial productivity of irregular past tense clusters be handled by subregular rules (e.g., 'change [I] to [^]'), some tied to specific lexical entries, others to phonological properties of classes of items (Halle & Mohanan, 1985). Others (e.g., Lieber, 1980; Pinker & Prince, 1988, 1991; Pinker, 1991; Marcus, Pinker, Ullman, Hollander, Rosen & Xu, 1992; Prasada & Pinker, 1993; Spencer, 1990) have suggested that the phonological patterns of irregular stems and their past tense forms come not from productive rules but from memory storage, where similar-sounding word pairs are superimposed in the memory representation and hence reinforce each other and enable occasional analogizing to new similar forms. In both of these theories, the phonological properties of a word, together with its lexical status as an irregular, are input to the inflection system. If a word is not listed as being irregular, and if it does not engage an irregular phonological pattern by virtue of its sound pattern, it is handled by the regular suffixation rule. Thus, these theories are rule-based in the sense that regular past tense mechanism acts as a default operation that applies to any verb that slips though the irregular filter.

In contrast, Rumelhart and McClelland's (1986) Parallel Distributed Processing model of the acquisition and use of the past tense of English captures the semi-productivity of irregular past tense inflection as well as the productivity of regular past inflection in a single, homogeneous network, using nothing but the phonological properties of the stems as input. A base form is represented by a pattern of activation within a vector of nodes each of which stands for a phonological property of the stem (e.g., a stop consonant at the beginning of the word; a high vowel between two voiced

segments). The network has an output vector with a similar structure, representing the computed past tense form of the verb. Every input node is connected to every output node by a connection with a modifiable weight. In a learning phase, the network is presented with a verb stem, represented as a set of activated input nodes, and produces an inflected form by activating a set of output nodes. A 'teacher' supplies the model with the correct past tense form for the stem, and the model adjusts the strength of the connections between the input and output nodes to minimize the difference between its computed output form and the correct past tense form. After the learning phase, the network can reproduce the past tense forms of the verb stems that it was trained on, and can generalize to many novel verbs on the basis of their phonological similarity to the verbs in the training set. Thus the model performed the stem-to-past tense mapping solely on the basis of phonological information. It captured patterns of phonological similarity for regulars and irregulars alike, generalizing in similar ways from *step* to *stepped* and from *cling* to *clung*. Because the model makes no qualitative distinction between irregular (lexically stored) and regular (rule-generated) past tense formation, and hence needs no information in its input to indicate the irregular status of irregular verbs, it does not implement formal linguistic notions such as 'verb root', 'rule', and 'lexical item'.

Other PDP models have followed the Rumelhart & McClelland (1986) model (Plunkett & Marchman, 1990, 1991; MacWhinney & Leinbach, 1991; Daugherty & Seidenberg, 1992; Hare & Elman, 1992), but they all have one thing in common: There is no special hardware dedicated to either regular or irregular inflection; both are handled in a single undifferentiated network. Thus, these models are often characterized as an alternative to symbol-processing or rule-based accounts of the acquisition and knowledge of language, and the relative success of these models present a challenge to a rule-based account of inflectional morphology.

Regularization by Derivation

Though these connectionist models of past tense inflection may be well-suited for handling the semi-productivity of lexically-based irregular inflection, much research in the past five years points to a qualitative difference between the psychological mechanisms underlying regular and irregular inflection (Kim, Pinker, Prince & Prasada, 1991; Marcus, et al., 1992; Prasada, Pinker & Snyder, 1990; Xu & Pinker, 1992;

Senghas, Kim, Pinker & Collins, 1992; Marcus, Brinkmann, Clahsen, Wiese, Woest & Pinker, 1993; Prasada & Pinker, 1993; Ullman, 1993; Kim, Marcus, Pinker, Hollander & Coppola, in press). In particular, this work implicates a system in which irregular past tense forms have some lexically stored component in the mental dictionary: They are linked to verb roots -- the irreducible form-meaning pairing that defines the basis of a family of verbs. Only if a verb is based on an irregular verb root will that verb have an irregular past tense form. Regular past tense formation, in contrast, has the status of a default operation -- it applies in all circumstances where an irregular verb root is not available (Pinker & Prince, 1988, 1991; Kim, et al., 1991; Pinker, 1991; Marcus, et al., 1993). Thus, the input to the past tense system must include information as to whether a word is based on an irregular root -- that is, information about its *morphological structure*. Undifferentiated connectionist models of inflection do not typically account for the effect of morphological structure on how words are inflected, and for good reason: This type of morphological structure is goes against the spirit of such models, at least in part because this abstract grammatical structure implicates a categorical difference between regular and irregular inflection. So such structure and its effects on the choice of inflection type must either be ignored, explained away, or expected to emerge from the patterns of acquired feature-to-feature mappings in these models.[15] In this section, I consider in some detail the effect of morphological structure on how words are inflected.

A denominal verb is a verb that is sensed by speakers to be derived from a noun. Denominal verbs uniformly have regular past tense forms, regardless of their phonology or semantics. Indeed, even if a denominal verb is homophonous with (or even ultimately derived from) an irregular verb, it will be regular, a phenomenon first noted by Mencken (1936) and given an explanation by Kiparsky (1982a, 1982b). (Examples are shown in (1); (a) and (b) are due to Paul Kiparsky; (c) - (j) are from Pinker and Prince (1988); see Kim, et al. (in press) for more examples.)

(1) a. He *grandstanded* to the crowd.	*grandstood
b. He *flied out* to center field.	*flew

[15]MacWhinney & Leinbach (1991) address phenomena relevant to the issue of the effect of morphological structure on inflection, but attempt to account for them by adding semantic nodes to the input representation of verbs. See Kim, et al. (in press) for relevant discussion of this aspect of their model. I will also consider this possibility in the General Discussion of this paper.

c. He *spitted* the pig.	*spat
d. He *braked* the car suddenly.	*broke
e. He *ringed* the city with artillery.	*rang
f. Martina *2-setted* Chris.	*2-set
g. He *sleighed* down the hill.	*slew
h. He *de-flea'd* his dog.	*de-fled
i. He *righted* the boat.	*rote
j. He *high-sticked* the goalie.	*high-stuck

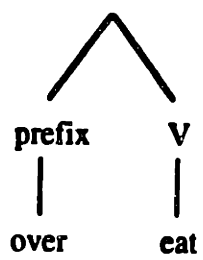
What these examples have in common is that the verbs are not directly constituted of verb roots; they are transparently based on nouns (the rough meanings in (2) correspond to the respective examples in (1)):

(2) a. to play to the *grandstand*
b. to hit a *fly* (ball) that gets caught (in baseball)
c. to put on a *spit*
d. to apply the *brakes*
e. to form a *ring* around
f. to beat in two *sets*
g. to travel in a *sleigh*
h. to remove *fleas*
i. to set *upright*
j. to hit with a *high stick*

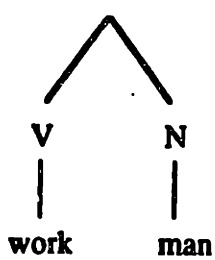
Regularization of denominal verbs is part of a more general phenomenon whereby the morphological structure of a verb determines its semantic, syntactic, and inflectional properties (Williams, 1981; Selkirk, 1982; Kim, et al., 1991; Pinker & Prince, 1991; Kim, et al., in press). In the constituent structure reflecting a word's derivation from more basic morphemes, one of these morphemes is generally the *head* of the word, and its properties percolate up to the word as a whole. In English, the head of the word is generally its rightmost element. Thus the head of *overeat*, whose structure is given in (3a), is the verb *eat*, so *overeating* is a kind of *eating* because it inherits the semantic properties of its head, *eat*, and it is a verb just as *eat* is a verb because it inherits the

grammatical category of its head, *eat*. Similarly, a *workman*, whose structure is given in (3b), is a noun referring to a kind of man, not a kind of work.

(3) a.



b.

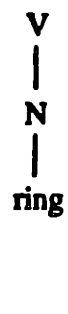


The conduit for information flow from the head to the top node of a word structure applies to *all* the information stored with the head (see Spencer, 1990, for qualifications to this statement, which are not relevant here). Not only does the grammatical category and meaning of the head percolate up (together with features like gender, humanness, animacy, and inherent aspect), but for irregular words, the lexically stored irregular past tense or plural form of the head percolates up as well. Thus the past tense of *overeat* is *overate*, and the plural of *workman* is *workmen*. This is also why we get irregularity preserved in novel forms like *out-sang*, *overshot*, *sawteeth*, *oil-mice* (Chinese peasants who scavenge uncollected oil from wells), *took a leak*, *blew him away*, *came into money*, and so on.

Some words, however, are headless, or 'exocentric': They differ in some property from their rightmost element, requiring that the usual pipeline of information from a word root to the word based on that root be blocked. For example, the structure in (4a), corresponding to the verb *ring* from *ringing the city*, shows a verb derived from a noun. Since the whole word, represented by its topmost label, is a verb, but the element it is made out of, *ring*, is a noun, it must be headless or 'exocentric', i.e., the grammatical category of the noun root "ring" in (4a) does not percolate up to the word based on that noun, namely the denominal verb "ring" -- if the noun *ring* were its head, *to ring* would have to be a noun, too, which it is not. Lacking a head and its associated data pipeline, the irregular form of the verb *to ring*, namely *rang*, cannot percolate up to be the past tense form of the whole word either. The regular *-ed* rule applies in its usual role as the

last resort, and thus we get *ringed.*

(4) a.



b.

Note that this machinery also operates in the verb *to fly out*, whose structure is given in (4b), even though the noun it comes from, *fly (ball)* (i.e. 'a baseball hit high in the air'), itself originally came from the irregular past tense verb *to fly* (i.e, 'to proceed through the air'). The step in the derivation that derives the verb *(to fly out)* from the noun *(fly ball)* yields an exocentric structure, as does the step in the derivation that derives the noun *(fly ball)* from the root verb *(fly)*. Therefore, the derived verb has no head and, consequently, has no pathway for the irregularity of the root it is based on to percolate up to the top node representing the word as a whole. What kills the irregularity of *fly out*, then, is its being a verb based on a word that is not a verb.[16]

In fact, not only does the regularization of denominal verbs fall out naturally and without stipulation as a consequence of independently needed representations, it applies more generally. That is, exocentric nouns, such as bahuvrihi compounds (a compound that refers to an object characterized by *having* rather than *being* the referent of its rightmost morpheme, e.g., *sabertooths/*saberteeth*), nouns derived from verbs (e.g., "She likes to give the boys a couple of quick *gooses/*geese*"), nouns derived from names (e.g., "There sure aren't many *Howlin' Wolfs/*Howlin' Wolves* on the blues music scene"), and many others (see Marcus, et al., 1993), have regular inflected forms even when they are homophonous with irregular plural nouns. Furthermore, the phenomenon applies to a wide range of languages as diverse as English and German on the one hand, and Arabic

[16]There are other formal grammatical theories that account for these phenomena (see Spencer, 1990 for a review). Most of these are consistent with the data from this paper, so this paper does not contribute to the debate about which of these is correct. Consequently, I will not discuss such alternatives in this paper.

on the other (McCarthy & Prince, 1990).

So the system of linguistic representations and a qualitative difference between lexically stored irregular past tense forms and the default rule-based nature of regular past tense formation capture a wide range of phenomena in a simple theory. These phenomena include how words are interpreted, what their grammatical categories are, and regularization by exocentrism in a wide range of cases both within and across languages.

Previous Studies on the Effects of Morphological Structure

This effect of morphological structure on how stems are inflected has been investigated in detail by Kim, et al. (1991). In an experiment with 32 college students, Kim, et al. (1991) investigated the role of phonology, grammatical structure, and semantic extendedness in adults' generalizations of past tense inflection. Subjects were asked to rate regular and irregular past tense forms of denominal and extended verbs which were homophonous with irregular verbs. An example is given in (5) and (6):

(5) *Denominal*: It's always a good idea to relax your clients by making sure they are supplied with food and drink at all times. That's why when MacTavish arrived, I immediately snacked him, drinked/drank him, and fed him.

(6) *Extended*: It's always a good idea to relax your clients by feeding them gossip and pretending to drink up the gossip they give you. That's why when MacTavish arrived, I immediately fed him lots of gossip, and drinked/drank up everything he said.

The findings supported the grammatical structure theory: Subjects rated regular past tense forms as better than irregular past tense forms for denominal verbs, but irregular past tense forms as better than regular past tense forms for extended verbs. These results were replicated with noncollege-educated adults, showing that the effect is not a consequence of formal language training that the college subjects might have received. Kim, et al. (1991) also collected data showing that the fact that denominal verbs are generally extended in meaning cannot explain these results.

Marcus, et al. (1993) find a similar result for regular and irregular plurals in German. The plural ending *-s* has the properties of the default regular rule in German, being the plural inflection applied to nouns derived from proper names and non-native noun stems. In their study, 40 native German-speaking subjects gave higher ratings for

the *-s* plural than for the best plural of the remaining possibilities for exocentric nouns (i.e., nouns derived from Names in their study), but lower ratings for the *-s* plural than for the best plural of the remaining possibilities for noun roots. Beyond replicating the results from Kim, et al. (1991), the additional interest of the studies in Marcus, et al. (1993) is that the default regular plural inflection in German is not the most frequent of the plural inflection types as it is in English; it is the *least* frequent of the plural types. This is problematic for any account of the acquisition of regular default inflection based solely on its frequency.

Kim, et al. (in press) replicated these general patterns of results with children. In four experiments, 70 3- to 10-year-old children were sensitive to morphological structure when they inflect nouns and verbs: They were more likely to produce regular inflected forms for denominal verbs like *to ring* ('to put a ring on') and exocentric nouns like the bahuvrihi compound *snaggletooth* (a kind of animal doll with big teeth) than for their homophonous irregular counterparts, even when these counterparts were extended in meaning. Children's inflectional systems thus seem to be like adults': Irregular forms are tied to the lexicon but regular forms are computed by a default rule, and words are represented as morphological tree structures reflecting their derivation from basic word roots which govern whether words with irregular sound patterns will be regularized. Furthermore, these results, together with an analysis of adult speech to children, suggest that morphological structure and a distinction between mechanisms for regular and irregular inflection is unlikely to be learned and may be inherent to the design of children's language systems.

The Logic of the Studies in this Paper

The studies in this paper test the effect of morphological structure on the computation of regular past tense verbs using an online past tense production measure. Here, I will present the logic underlying the studies.

Suppose that clusters of irregular past tense verbs have an effect on the time it takes to produce the past tense form of a rhyming regular past tense verb root. That is, suppose that it takes longer to produce the past tense form *baked* given the verb stem *bake* than it takes to produce the past tense form *paused* given the verb stem *pause* because *bake* rhymes with the irregular past tense verbs *wake, make, awake, break, take, mistake, forsake, shake* and *partake* whereas *pause* does not rhyme with any irregular past tense

verbs. A reason to believe that there may be such an effect is that, as we have already seen, the phonological properties of clusters of irregular past tense verbs play a part in the semi-productivity of those clusters; this semi-productivity of irregular past tense clusters may then interfere in the computation of the past tense forms of rhyming regular past tense verbs.

There are a number of mechanisms that might underly such an effect. One possibility is that all past tense forms are actually computed by a single, undifferentiated mechanism and that strong connections between regular past tense verbs and the irregular past tense verbs that rhyme with them slow down the computation of the correct past tense forms for these regular past tense verbs; no such interference would exist for regular past tense verbs that do not rhyme with irregular past tense verbs.[17] I will call this the *single mechanism account.*

Another possibility is that irregular past tense forms are lexically stored and regular past tense forms are generated by rule, but some online mechanism that is responsible for producing the past tense forms of verbs checks whether there is any possibility that a verb has an irregular past tense form given its phonological properties. So all available mentally represented information may be used online to determine the past tense forms of verbs, including information about the phonological similarity of regular past ter se verbs to clusters of irregular past tense verbs. If this were the case, then this checking mechanism might classify regular past tense verbs that rhyme with irregular past tense verbs as potential irregular past tense verbs based on phonological information. This might then lead to interference for applying the regular past tense rule, resulting in longer production times for the past tense forms of regular past tense verbs that rhyme with irregular past tense verbs than for those that don't; as with the single mechanism account, no such interference would exist for regular past tense verbs that do not rhyme with irregular past tense verbs. I will call this the *dual mechanism account.*

I will not be directly concerned with the details of the underlying source of this effect, though under both the single and dual mechanism accounts it is presumably due in

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[17]Such effects were reported by Daugherty and Seidenberg (1992) in their single-network model of the acquisition and use of the English past tense system also demonstrated a similar property: The model made more errors in the generation of regular past tense verbs that were phonologically similar to irregular past tense verbs than for regular past tense verbs that were not similar to irregular past tense verbs. This could be translated into a similar difference in reaction times.

some way to an effect of irregular past tense verbs on the mechanism that computes or produces the regular past tense forms of verbs; for the purposes of this paper, it is only important that such an effect exists. If such an effect does exist, then one can ask the question whether it can be attenuated in certain circumstances with the hope of providing data pertaining to the question of how information flows during the online computation of regular past tense forms. One plausible candidate circumstance in which such attenuation may occur is one in which there is a structural reason that the verb categorically *cannot* have an irregular past tense form, as in the case of denominal verbs. That is, if the morphological structure of denominal verbs is computed before the influence of irregular past tense verbs is exerted and if the knowledge that prevents such verbs from having irregular past tense forms is relevant for directing the flow of information during the online computation of the past tense forms of verbs, then the effect that clusters of irregular past tense verbs have on the time it takes to produce the past tense form of rhyming regular past tense verb roots may be significantly reduced for denominal verbs. The intuition underlying this hypothesis is that checking whether a denominal verb is phonologically similar to irregular past tense verbs is a useless step in the computation of its past tense form because denominal verbs can never have irregular past tense forms. I will call this the *structure-in-time* hypothesis -- the hypothesis that structure affects real-time processing, and that the structure is computed and utilized "in time", i.e., before the phonological information that gives rise to the effect of irregular past tense verbs on the production of regular verb roots plays a role.

There are three things worth noting. First, the motivation for the structure-in-time hypothesis is not just that denominal verbs have regular past tense forms. After all, this is true by definition of regular past tense verb roots as well. The intuition underlying the structure-in-time hypothesis is that the properties of inflectional morphology that are part of the inherent design of the inflectional system may be implemented in performance systems (such as the past tense production system) in a way that reflects this inherent design; on the other hand, the properties of inflectional morphology that are accidental will not be. The verb roots that have regular past tense forms have regular past tense forms for (largely) accidental reasons. That is, any particular verb root has a regular past tense form in part because of the linguistic input available to the language learner; given a different linguistic environment (e.g., one in which children hear, say, "jamp" as the

past tense form of "jump"), any given regular past tense verb root could have had an irregular past tense form.[18] Thus, the prediction of an effect of irregular past tense verbs on the time it takes to produce the past tense forms of regular verb roots is based on the claim that there is no reason inherent to the design of the inflectional system that any particular verb root *has* to have a regular past tense form; that is, no structural reason categorically prevents verb roots from having irregular past tense forms. On the other hand, the fact that the structure of denominal verbs forces them to have regular past tense forms is taken to be not just an accidental property of any particular language under consideration, but an inherent property of the inflectional system, a claim that is supported by the wide range of cases in which headless stems categorically have regular inflection, as noted above. Thus, the prediction of a non-effect of clusters of irregular past tense verbs on the time it takes to produce the past tense forms of denominal verbs is based on the claim that the inherent organization of the morphological system would never allow a denominal verb to have an irregular past tense form.

Second, though the structure-in-time hypothesis is consistent with the dual mechanism account, it is not obvious how it can be reconciled with the single mechanism account. That is, there is no obvious way to access just the part of a single, undifferentiated inflectional mechanism that generates regular past tense forms. In fact, doing so goes against the spirit of the single mechanism account: Because there is no qualitative difference between regular and irregular inflection, no grammatical processes should be able to single out regular inflectional morphology. But the fact that denominal verbs categorically have regular past tense forms depends on such a distinction. So if the structure-in-time hypothesis is correct, it presents a challenge for the single mechanism account: It must show how such a pattern of data could be accounted for without using morphological structure to categorically single out regular past tense formation. Such a pattern has to be shown to arise from the statistical properties of the linguistic environment available to the learner. I will consider this point in detail in the General Discussion.

Third, there is no particularly strong reason to believe that the predictions of the structure-in-time hypothesis have to be borne out, even if morphological structure is, in

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[18]This is not to say that the productivity of regular past tense forms is not due to the existence of a regular past tense rule. I do take this to be inherent to the design of the inflectional system.

fact, mentally represented (hence, the *structure-in-time* hypothesis and not the *psychological-reality* hypothesis). The issue of psychological reality is really just the question of whether linguistic structures are mentally represented, which does not depend on any particular measure of such a claim insofar as the additional assumptions that link the measure to claim are weak, as they are here. Thus, finding evidence that supports the structure-in-time hypothesis would constitute a discovery about the mechanisms responsible for the online computation of regular past tense forms; it is not a necessary or logical consequence of a theory which represents regular and irregular inflection using distinct mechanisms. In fact, there would be no obvious problem for the dual mechanism account if the structure-in-time hypothesis turned out to be false. Such a finding would just mean that the morphological structure of verbs is irrelevant for the online mechanisms that compute the past tense forms of verbs. That is, nothing other than the structure-in-time hypothesis itself is at stake if the structure-in-time hypothesis turns out to be false. On the other hand, if the structure-in-time hypothesis is correct, this does speak to the issue of the psychological reality of morphological structure, linguistic representations, and regular inflectional rules because the structure-in-time hypothesis crucially depends on the existence of such structures.

So two sources of information that might be used in the online computation of regular past tense forms are information about whether the verb is phonologically similar to irregular past tense verbs, and information about whether the verb's morphological structure dictates that the verb must have a regular past tense form. Experiment 1 tests whether or not there is an effect of irregular past tense verbs on the time it takes to produce the past tense form of regular past tense verb roots. Experiment 2 tests the structure-in-time hypothesis, i.e., whether the effect found for verb roots in the first study is significantly diminished for denominal verbs. Experiment 3 controls for a possible confound in the second study.

Experiment One

If the production of the past tense form of a regular past tense verb root is affected by its phonological similarity to irregular past tense verbs, then one would expect subjects to take more time to initiate production of the past tense forms of regular past tense verb roots that rhyme with irregular past tense verbs than those that do not rhyme with

irregular past tense verbs. This experiment tests whether clusters of irregular past tense verbs exert such an effect (which is a precondition for showing that such an effect can be diluted for denominal verbs, the issue addressed by Experiment 2).

Method

Subjects. Fifteen native English-speaking adults were subjects in the experiment. They were paid for their participation.

Materials and Design. The items consisted of eighteen pairs of monosyllabic regular past tense verb roots. None of these verbs were homophonous with any irregular past tense verb. One verb in each pair of items rhymed with an irregular past tense verb; the other did not.[19] Each pair of verbs was matched in length and in overall frequency of the verb form (including stem, progressive, participle, present and past forms) using the frequency counts in the Associated Press News counts.[20] Nine of the eighteen pairs of items were also used in Experiments 2 and 3. The full set of eighteen pairs of verbs from this experiment is listed in Appendix A.

A block of practice items consisting of 10 irregular past tense verbs preceded the experiment. There were 36 regular past tense verb fillers and 97 irregular past tense verb fillers which were randomly mixed with the experimental items such that each subject saw the items in a different order. So overall, subjects saw 72 regular past tense verbs and 107 irregular past tense verbs. The large number of irregular past tense verb fillers was used to ensure that subjects did not simply invoke a strategy of adding *-ed* to the end of the verb stems to form their past tense responses since such a strategy would generate the correct response for all experimental items and could lead to a floor effect.

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[19]All experimental items in all the studies in this paper that are in the rhyming condition literally have the same rhyme as some irregular past tense verb; experimental items that are in the non-rhyming condition not only do not have identical rhymes as any irregular past tense verb, but were chosen such that their rhymes are dissimilar from any irregular past tense verb except where noted.

[20]The Associated Press News counts come from the full 1988 AP News wires (starting in February 1988), which total about 44 million words. After this 44 million word corpus had been analyzed by Ken Church's stochastic part-of-speech analyzer, 435,082 word/position types emerged. That is, there are 435,082 distinct types in the corpus, as defined by Church's program. These counts were used instead of the Francis and Kucera (1982) counts because the sample of written text in the Associated Press counts is far greater than the one million words of written text that the Francis and Kucera counts are based on. Using the larger AP corpus was necessary in order to obtain reliable frequency measures for some of the low frequency denominal verbs and verb roots used in the experiments reported in this paper.

Procedure. Each experimental trial consisted of the presentation of a verb to which subjects were asked to produce the past tense form as quickly and accurately as possible. Each trial proceeded as follows: A fixation ("+") appeared on the computer screen that indicated the position in which a verb would subsequently appear. After 1250 milliseconds, the fixation disappeared and was immediately replaced by a verb. The verb remained on the screen for 200 milliseconds at which point it was replaced by a mask ("############"). The mask remained on the screen until the subject said the past tense form of the verb into a microphone, thus activating a voice trigger. The voice trigger measured the time from the initial presentation of the verb to the subjects' initiation of their past tense response. The next trial (including the 1250 millisecond presentation of the fixation) started 200 milliseconds after the activation of the voice trigger.

The subjects' responses were tape recorded. The experimenter also remained in the room with the subjects to record (i) the subjects' errors, (ii) when the subjects' responses did not activate the voice trigger, and (iii) when extraneous noises preceding the subjects' responses activated the voice trigger. These items and the items matched with them on length and frequency were eliminated from the analyses of reaction times. Only the subjects' errors were included in the error analyses.

Results

The mean response time for the 18 verb roots that rhymed with irregular past tense verbs (865.93 msec) was greater than the mean response time for the 18 verb roots that did not rhyme with irregular past tense verbs (747.19 msec). This difference was significant in separate one-way ANOVAs with Rhyme/NonRhyme as the independent variable, one with Subjects as the random variable ($F1(1,14) = 19.47$, $p < .001$), and the other with Items as the random variable ($F2(1,17) = 9.48$. $p < .01$). Subjects made eight errors for Rhyme condition verbs, but only one for NonRhyme condition verbs. Therefore, a speed-accuracy tradeoff cannot explain the effect of the Rhyme/NonRhyme variable: Subjects made more errors in the slower condition.

Though the verbs were matched on overall frequency of use as a verb, one might ask whether the time to produce the regular past tense form of a verb also depends on the relative frequencies of the past tense forms themselves as well. That is, though the

Rhyme/NonRhyme pairs of verbs were matched on overall verb frequency, maybe the Rhyme condition verbs all had lower past tense frequencies than their corresponding NonRhyme condition counterparts, thus leading subjects to produce the regular past tense forms of the Rhyme condition verb roots more slowly than the regular past tense forms of the NonRhyme condition verb roots in this experiment. To control for this possibility the analyses reported above were done for the eight pairs of items that had the same or higher past tense frequencies for their Rhyme condition members than for their NonRhyme condition members. The mean response time for the eight Rhyme condition verb roots (913.92 msec) was greater than the mean response time for the eight NonRhyme condition verb roots (777.68 msec). This difference was significant in separate one-way ANOVAs, one with Subjects as the random variable ($F1(1,14) = 9.19$, $p < .01$), and one with Items as the random variable ($F2(1,7) = 5.60$, $p < .05$). For these eight pairs of items, subjects made only three errors in the Rhyme condition but none in the NonRhyme condition.

For the nine pairs of items in this experiment that were also used in Experiment 2, the mean response time for the verb roots that rhymed with irregular past tense verbs (823.20 msec) was greater than the mean response time for the verb roots that did not rhyme with irregular past tense verbs (745.34 msec). This difference was significant in separate one-way ANOVAs, one with Subjects as the random variable ($F1(1,14) = 11.32$, $p < .005$), and the other with Items as the random variable ($F2(1,8) = 5.42$, $p < .05$). For these nine pairs of items, subjects made only one error in the Rhyme condition but none in the NonRhyme condition.

Though none of the verbs in the NonRhyme condition literally rhymed with irregular past tense verbs, two verb roots in that condition ended in *t* or *d* (i.e., *weld, wilt*). Since all irregular past tense verbs whose past tense forms are phonologically identical to their stem forms also have this property, it might be argued that this item was misclassified with respect to the Rhyme/NonRhyme variable. But such a misclassification would bias *against* finding a difference between the Rhyme and NonRhyme conditions. Therefore, the significant difference between the Rhyme and NonRhyme conditions speaks to the robustness of the effect.

Discussion

It takes subjects more time to initiate the production of the past tense form of a verb root if it rhymes with an irregular past tense verb than if it does not.[21] This result indicates that the phonological properties of irregular past tense verbs exert an influence on the time it takes to produce the past tense forms of regular past tense verb roots (measured here by identity of rimes): The closer regular past tense verb roots are phonologically to irregular past tense verbs, the slower people are to produce their regular past tense forms. The source of this effect, as mentioned earlier, is consistent with both the single and the dual mechanism accounts of past tense inflection. Its importance in this paper is that it sets the stage for studying the structure-in-time hypothesis. That is, can this effect of irregular past tense verbs on the time it takes to produce the past tense forms of regular past tense verbs be significantly reduced or eliminated when the morphological structure of a verb dictates that the verb cannot have an irregular past tense form?

Experiment Two

This experiment tests the structure-in-time hypothesis directly. If structural information directs the flow of information during the computation of the past tense forms of denominal verbs, then we should replicate the results from Experiment 1 for verb roots, but find an attenuation of this effect for denominal verbs. That is, if the structure-in-time hypothesis is correct, then upon recognizing that a verb has a denominal structure, the mechanisms that compute its past tense form will be able to ignore the phonological similarity of the verb to irregular past tense verbs, the presumed basis for the effect found in Experiment 1. Recall that this is because the headless structure of denominal verbs categorically does not allow irregularity features of the verb root that the denominal verb is based on to percolate up to the denominal verb as a whole, and this knowledge may be directly reflected in the online past tense production mechanisms. Such a finding would speak both to the issue of whether such linguistic representations exist and to the issue of how such representations are used online by the past tense production system.

There are at least two methodological reasons that one might not expect to find a

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[21] Seidenberg and Bruck (1990) and Ullman (1993) find a similar result.

reduction of the effect in Experiment 1 for denominal verbs. First, the denominal structure of the verb has to be computed. Second, the denominal structure of the verb has to be computed in time (i.e., before the mechanisms that give rise to the phonological effect in Experiment 1 exert their influence). Failure to meet these criteria would be a reason for not finding the structure-in-time effect even if the structure-in-time hypothesis is correct. In a pilot study testing the structure-in-time hypothesis that used the same methodology as that in Experiment 1, neither of these criteria were clearly met. So subjects were simply presented with verbs -- some verb roots and some denominal verbs -- on a computer screen, and they were asked to produce the past tense forms of the verbs as quickly and as accurately as possible. The problem with that pilot study is that it is not clear that the subjects computed the structure of the denominal verbs for which they produced the past tense forms. This was evident because subjects were clearly taken aback by being asked to produce the past tense forms of denominal verbs such as *milk*. The typical reaction of the subjects to the study was that many words they saw were not verbs at all; they were nouns. Sometimes subjects reported trying to come up with a context in which the "nouns" that appeared on the screen could be used as verbs, a strategy that greatly elevated response times for denominal verbs. Sometimes subjects reported just treating the denominal verbs as sounds and producing their past tense forms by adding "-ed" to them. The problem with such a strategy is that it eliminates the reasons for expecting the structure-in-time effect: The *structure* of denominal verbs is claimed to be the basis of the structure-in-time effect; if subjects treated denominal verbs as pure sounds, then these structures were presumably not computed and, consequently, the online past tense production mechanism will not be licensed to bypass the effect of irregular past tense verbs on production times. These problems were overcome in the present study by placing the verbs in the experimental trials in the first of a pair of context sentences, thus making the intended interpretation of the denominal verb clear to the subjects well before they produced its past tense form. Since the interpretation of denominal verbs depends on their proper morphological analysis, this method of stimulus presentation guarantees that subjects computed the headless structures of denominal verbs.

Method

Subjects. Fourteen native English-speaking adults were subjects in the experiment. They were paid for their participation.

Materials and Design. The items consisted of nine quadruples of monosyllabic regular past tense verbs. None of these verbs were homophonous with any irregular past tense verbs. In each quadruple of items, two verbs were denominal verbs and two were verb roots; the verb roots were half of those from Experiment 1. Furthermore, in each quadruple of items, one of the denominal verbs rhymed with an irregular past tense verb and the other did not; one of the verb roots rhymed with an irregular past tense verb and the other did not. The verbs in a quadruple were matched in length and in overall frequency of their usage as verb forms using the frequency counts in the Associated Press lists.

Each verb was presented in its stem or present tense form in the first sentence of a two sentence context, i.e., without overt inflection. Sentence contexts were used to ensure that subjects analyzed denominal verbs as verbs, and not as nouns. For each quadruple of verbs, the number of words in each of the two sentences in the contexts was matched. The serial position of the verb in the first sentence of the context was constant across each member of a quadruple; the verb was never in the second sentence.[22] The full set of nine quadruples of verbs and their respective contexts are listed in Appendix B.

A block of practice items consisting of three irregular past tense verbs preceded the experiment. There were four blocks of items, each with experimental and filler items randomized within it, such that the first three items were filler items. Each of the four blocks contained one member of each quadruple of items such that an equal number of rhyming denominal verbs, non-rhyming denominal verbs, rhyming verb roots, and non-rhyming verb roots was in each block.[23] Each subject saw the four blocks in a different order such that each of the four blocks showed up in the each of the four

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[22]Often, the verbs in a quadruple had different subcategorization frames and selectional restrictions, thus eliminating the possibility of rotating the verbs of a quadruple through a set of contexts. This problem is due largely to the fact that there were few verbs in the language that had all the right properties for constructing the quadruples.

[23]Each block actually had two of each of these types of items and three of the other since there were 9 quadruples of items.

positions an equal number of times.

The fillers consisted of 20 regular past tense verbs and 56 irregular past tense verbs (along with their respective contexts). Eight of the regular past tense verb fillers had the verb in the second sentence; twelve of the regular past tense verb fillers did not have the verb in the context at all. Twelve of the irregular past tense verb fillers had the verb in the first sentence; 24 of the irregular past tense verb fillers had the verb in the second sentence; 20 of the irregular past tense verb fillers did not have the verb in the context at all. So subjects produced the past tense forms of an equal number of regular and irregular past tense verbs (i.e., 56 each). The large number of irregular fillers was included in order to prevent subjects from invoking a strategy of adding *-ed* to the end of the verb stems to form their past tense responses since such a strategy would generate the correct response for all experimental items and could lead to a floor effect. Furthermore, the verb that subjects were asked to produce the past tense forms of was in the first context sentence 48 times, in the second context sentence 32 times, and not in either context sentence 32 times. The large number of contexts that did not include the target verb in the first sentence was included so that subjects could not guess which verb in the context (if any) would be the one for which they would be asked to produce the past tense form. Each of the four block contained an equal number of each filler type.

Finally, a comprehension question was constructed for each trial. Half of these had a "yes" response and half of these had a "no" response. These were included to ensure that subjects were reading the context sentences.

Procedure. Each experimental trial consisted of three parts: The first was a whole-sentence self-paced reading task for the two context sentences; the second was the presentation of verb of which subjects were asked to produce the past tense form as quickly and accurately as possible; the third part was the presentation of a comprehension question for the trial's context passage. Each trial proceeded as follows: A fixation ("+") appeared on the computer screen that indicated the line on which the first sentence of a context would subsequently appear. After 1000 milliseconds, the fixation disappeared and was replaced immediately by the first sentence in the passage. This sentence remained on the screen until the subject pressed a button after reading sentence, at which point the sentence disappeared and the second sentence of the passage appeared with no delay. This sentence remained on the screen until the subject pressed the button again

after reading the sentence, at which point the sentence disappeared and a second fixation appeared with no delay. The fixation remained on the screen for 400 milliseconds and was then replaced by a verb. The verb remained on the screen for 200 milliseconds at which point it was replaced by the mask ("##########"). The mask remained on the screen until subjects said the past tense form of the verb into a microphone, thus activating a voice trigger. The voice trigger measured the time from the initial presentation of the verb to the subjects' initiation of their past tense response. Immediately after the voice trigger was activated, the comprehension question appeared. Subjects responded to this question using one button to indicate a "yes" response and another button to indicate a "no" response. The next trial (including the 1000 millisecond fixation) started 1000 milliseconds after the subjects' response to the comprehension question. At the end of each of the first three blocks, subjects were instructed to take a short break.

The subjects' responses were tape recorded. The experimenter also remained in the room with the subjects to record (i) the subjects' errors, (ii) when the subjects' responses did not activate the voice trigger, and (iii) when extraneous noises preceding the subjects' responses activated the voice trigger. These items and the three items matched with them in length and frequency were eliminated from the analyses of reaction times. Items for which subjects responded incorrectly to the comprehension question and the items matched with them in length and frequency were eliminated from all analyses. Subjects who missed more than 75% of the comprehension questions for the experimental items were eliminated from the analyses. Two of the fourteen subjects were eliminated in this way. Only the subjects' errors were included in the error analyses.

Subjects were asked what they thought the experiment was about. Of the verbs that subjects were asked to produce the past tenses of, no subject reported noticing that some of the verbs were related to nouns or that some of the regular past tense verbs rhymed with irregular past tense verbs. Subjects also did not notice that the verbs they were asked to produce the past tense forms of appeared in the first context sentence (i.e., 48 times) more often than they appeared in the second context sentence (i.e., 32 times) or more often than they did not appear in either context sentence (i.e., 32 times). Subjects reported that some verbs had regular past tense forms and that others had irregular past tense forms, that the verb was sometimes in the context and sometimes it was not, and

that the verbs that were not in the contexts were sometimes thematically related to the context;[24] none of these factors would bias the subjects to respond in accordance with the structure-in-time hypothesis.

Results

The mean response time for the verbs in the Rhyme condition (861.13 msec) was greater than the mean response time for the verbs in the NonRhyme condition (767.07 msec). This difference was significant in separate two-way ANOVAs with Subjects as the random variable ($F1(1,11) = 12.38, p < .005$), and with Items as the random variable ($F2(1,8) = 25.89, p < .001$).

The mean response time for the verb roots that did not rhyme with irregular past tense verbs was much greater than the mean response time for the verb roots that rhymed with irregular past tense verbs, whereas the mean response time for the denominal verbs that did not rhyme with irregular past tense verb was only slightly greater than the mean response time for the denominal verbs that rhymed with irregular past tense verbs. The means are given in Table 1 and shown in Figure 1. This shows that the significant main effect reported above speaks to the strength of the Rhyme/NonRhyme effect for verb roots since the denominal verbs diluted the Rhyme/NonRhyme difference by showing virtually no difference between the Rhyme (803.08 msec) and NonRhyme (798.77 msec) conditions.

Insert Table 1 about here

Insert Figure 1 about here

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[24]This was not part of the design of the experiment, but was accidentally true of several of the fillers.

In separate two-way ANOVAs with Denominal/Root and Rhyme/NonRhyme as the independent variables, the Denominal/Root x Rhyme/NonRhyme interaction was significant with Subjects as the random variable ($F1(1,11) = 8.70, p < .02$) and with Items as the random variable ($F2(1,8) = 7.31, p < .03$). Subjects made no past tense production errors on any of the experimental items. This is consistent with the low error rates in Experiment 1 for the verb roots that were in both Experiments 1 and 2.

To see if the response times for verb root items in the Rhyme and NonRhyme conditions were significantly different, separate one-way ANOVAs with Rhyme/NonRhyme as the independent variable were performed for only the verb root items, one with Subjects as the random variable, and one with Items as the random variable; both analyses show a significant main effect of the Rhyme/NonRhyme condition for verb roots ($F1(1,11) = 12.52, p < .005$; $F2(1,8) = 34.75, p < .001$). These results replicate the effect from Experiment 1 with a different methodology. To see if this effect holds up for verb roots with higher past tense frequencies in the Rhyme condition than in the NonRhyme condition, these analyses were done for the three verb root items that had higher past tense frequencies for the verb roots in the Rhyme condition than for their respective counterparts in the NonRhyme condition. The mean response time for the three verb roots in the Rhyme condition (838.46 msec) was greater than the mean response time for the three verb roots in the NonRhyme condition (670.36 msec). This difference was significant in a one-way ANOVA with Subjects as the random variable ($F1(1,11) = 11.12, p < .01$), and marginally significant in a one-way ANOVA with Items as the random variable ($F2(1,2) = 15.74, p = .058$).

There are three possible reasons that these results do not support the structure-in-time hypothesis. First, some of the denominal verbs in the Rhyme condition may have been misclassified. That is, if denominal verbs that were classified in the Rhyme condition but are sufficiently close to irregular past tense verbs that they should have been classified in the NonRhyme condition, then this might have the effect of eliminating a Rhyme/NonRhyme difference in past tense production times. Second, Rhyme/NonRhyme pairs of denominal verbs were matched on overall frequency of use as verbs. But if past tense frequencies play a role in the production of the past tense forms of verbs above and beyond the overall frequency of the verbs, then this confound might have cancelled out a Rhyme/NonRhyme difference in past tense production times.

Third, because denominal verbs are derived from nouns, the noun frequencies may play a role in the production of the past tense forms of verbs above and beyond the overall frequency of usage as verbs. This confound might have cancelled out a Rhyme/NonRhyme difference in past tense production times. I will consider each of these possibilities in turn.

Misclassification of denominal verbs

Though none of the verbs in the NonRhyme condition literally rhymed with irregular past tense verbs, one denominal verb in that condition ended in *t* or *d* (i.e., *cart*). Since all irregular past tense verbs whose past tense forms are identical to their stem forms also have this property, it might be argued that this item was misclassified with respect to the Rhyme/NonRhyme variable thus increasing the reaction time for the Denominal/NonRhyme condition and unfairly contributing to the significant Denominal/Root x Rhyme/NonRhyme interaction reported above.[25] Though such a misclassification may have had an effect of some sort, the significant interaction is not entirely due to this item because the pattern of results and the results of the two-way ANOVAs remain essentially unchanged if this verb and the three verbs that were matched with it in length and frequency (i.e., *sin, whirl, thaw*) are eliminated from the analyses ($F1(1,11) = 8.55$, $p < .02$; $F2(1,7) = 7.27$, $p < .04$). In fact, the mean reaction time for the Rhyme condition (797.67 msec) is *faster* than for the NonRhyme condition (800.30 msec) for denominal verbs; this is exactly the opposite pattern of results than what the misclassification criticism predicts. The means are given in Table 2.

Insert Table 2 about here

The effect of past tense frequencies

A different potential source of the non-difference between the Rhyme condition and

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[25]Again, the verb root items that ended in *t* or *d* were not eliminated from the analyses because just as they bias against finding an effect in Experiment 1, they also bias against the predictions of the structure-in-time hypothesis.

the NonRhyme condition for denominal verbs is the frequency of their past tense forms: If the frequencies of the past tense forms of the denominal items exerted an effect above and beyond the overall frequency of use as verbs, then a high past tense frequency for Denominal/Rhyme condition verbs relative their corresponding Denominal/NonRhyme condition verbs might have offset a difference in reaction time due to irregular past tense verbs between the Denominal/Rhyme and Denominal/NonRhyme conditions. That is, maybe irregular past tense verbs do have an effect on the time it takes to produce the past tense forms of denominal verbs, but a confounding difference in past tense frequencies in the opposite direction might have cancelled out the effect in this experiment.

A regression analysis indicates that such an effect of past tense frequencies is not the source of the significant Denominal/Root x Rhyme/NonRhyme interaction: For each pair of Rhyme/NonRhyme denominal verbs in this experiment, the difference between the log of the frequency of the past tense form of the Denominal/Rhyme condition verb and the log of the frequency of the past tense form of the Denominal/NonRhyme condition verb was the predictor variable;[26] the difference between the mean response times for each Denominal/Rhyme condition verb and its corresponding Denominal/NonRhyme condition verb was the dependent variable. If there is an effect of past tense frequency on subjects' response times, this should show up as a negative correlation between the two variables: The greater the log of the past tense frequency for the Rhyme condition denominal verbs relative to that for the NonRhyme condition denominal verbs, the faster subjects' responses to the Rhyme condition denominal verbs should be relative to the NonRhyme condition denominal verbs. This does not turn out to be the case: The correlation between these two factors was negligible ($r = 0.09$, $F(1,7) = 0.05$, $p > .8$).

The effect of noun frequencies

Yet another potential source of the non-difference between the Rhyme condition and the NonRhyme condition for denominal verbs is the frequency of the nouns from which the denominal verbs were derived: Though the verbs were matched on frequency of usage as verbs, denominal verbs, by definition, also have a non-zero, and often large,

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[26]Actually, log[past tense frequency + 1] was used in this particular analysis because the past tense frequency of one verb was zero, and the log of zero is mathematically undefined.

frequency as nouns. So if the Rhyme condition denominal verbs have higher corresponding noun frequencies than the NonRhyme condition denominal verbs, then this noun frequency difference may have been enough to offset a difference in reaction time due to irregular past tense verbs between Rhyme condition denominal verbs and NonRhyme condition denominal verbs. That is, maybe irregular past tense verbs do have an effect on the time it takes to produce the past tense form of denominal verbs, but a confounding difference in the frequencies of the nouns they were derived from in the opposite direction might have cancelled out the effect in this experiment.

Though there does seem to be an effect of noun frequency, it does not appear to be the source of the significant Denominal/Root x Rhyme/NonRhyme interaction. Though three of the denominal pairs of items have a higher noun frequency for their Rhyme condition verb than for their NonRhyme condition verb (i.e., *sin* > *cart; root* > *stack; hand* > *fish*), six of the denominal pairs of items have a *lower* noun frequency for their Rhyme condition verb than for their NonRhyme condition verb (i.e., *spear* < *cage; claw* < *wax; steam* < *bus; loot* < *whip; brand* < *cap; spike* < *milk*). So, by parity of argument, if noun frequency increases the reaction time for the Denominal/Rhyme verbs relative to the Denominal/NonRhyme verbs in the former three pairs of items, it should *decrease* the reaction time for the Denominal/Rhyme verbs relative to the Denominal/NonRhyme verbs in the latter six pairs of items.

This turns out to be the case, at least qualitatively. Looking at the three quadruples of items whose Denominal/Rhyme condition verbs have a higher noun frequency than their corresponding Denominal/NonRhyme condition verb, subjects' mean response time for Denominal/Rhyme verbs was 97.82 msec lower than for the Denominal/NonRhyme verbs. The means are given in Table 3 and shown in Figure 2.

Insert Table 3 about here

Insert Figure 2 about here

The six quadruples of items whose Denominal/Rhyme condition verbs have a lower noun frequency than their corresponding Denominal/NonRhyme condition verb showed the opposite pattern of results: Subjects' mean response time for Denominal/Rhyme verbs was 50.23 msec greater than for the Denominal/NonRhyme verbs. The means are given in Table 4 and shown in Figure 3.

Insert Table 4 about here

Insert Figure 3 about here

Though the means for the six quadruples of items whose Denominal/Rhyme condition verbs have a lower noun frequency than their corresponding Denominal/NonRhyme condition verbs goes against the strongest predictions of the structure-in-time hypothesis (i.e., that the Rhyme/NonRhyme difference is eliminated for denominal verbs), this pattern of results for these six quadruples of items may be due solely to the effect of noun frequencies. That is, the empirical reason for believing that noun frequencies have an effect at all is that it accounts for the difference between these six items and the three items whose Denominal/Rhyme condition verbs have a higher noun frequency than their corresponding Denominal/NonRhyme condition verbs. If anything, the true difference between Denominal/Rhyme response times and Denominal/NonRhyme response times is likely to lie somewhere between this difference for the former six items (50.23 msec) and that for the latter three items (-97.82 msec). It is important to note that any number in this range is still much smaller than 183.81 msec, the difference between Verb Root/Rhyme response times and Verb Root/NonRhyme response times from this experiment.

To investigate the effect of the frequency of the nouns that denominal verbs are derived from further, the following regression analysis was performed: For each pair of Rhyme/NonRhyme denominal verbs from this experiment, the difference between the log of the frequency of the noun that the Denominal/Rhyme condition verb was derived from and the log of the frequency of the noun that the Denominal/NonRhyme condition verb was derived from was the predictor variable; the difference between the mean response times for each Denominal/Rhyme condition verb and its corresponding Denominal/NonRhyme condition verb was the dependent variable. If there is an effect of noun frequency on subjects' response times, this should show up as a negative correlation between the two variables: The greater the log of the noun frequency for the Rhyme condition denominal verbs relative to the NonRhyme condition denominal verbs, the faster subjects' responses to the Rhyme condition denominal verbs should be relative to the NonRhyme condition denominal verbs. This turns out to be the case: The correlation between these two factors was marginally significant (r = -0.64, $F(1,7)$ = 4.92, p = .06), which corroborates the claim that the frequencies of the nouns that the denominal items in this experiment are derived from have an effect on subjects' response times for producing the past tense forms of the denominal verbs.

Furthermore, the regression equation from this analysis can be used to estimate the Rhyme/NonRhyme response time difference for denominal verbs if the difference between log[Denominal/Rhyme noun frequency] minus log[Denominal/NonRhyme noun frequency] were zero (i.e., if the frequencies of the nouns that the denominal verbs in this experiment were derived from could have been controlled perfectly). The regression equation is:

(10) $Y = -21.02X - 2.54$

where $X = \log[\text{Noun Freq, Rhyme}] - \log[\text{Noun Freq, NonRhyme}]$

$Y = RT[\text{Rhyme}] - RT[\text{NonRhyme}]$

So if the noun frequencies of the Rhyme/NonRhyme denominal pairs were controlled perfectly (i.e., if $X = 0$), then the regression equation estimates that the difference in response time between Denominal/Rhyme verbs and Denominal/NonRhyme verbs would have been -2.54 msec. So by this estimate, the response times for denominal verbs in the Rhyme and NonRhyme conditions are virtually

identical, as is the case for the actual response time means for denominal verbs (see Table 1 and Figure 1). In fact, by this estimate, the response time for Rhyme denominal verbs is slightly *faster* than that for NonRhyme denominal verbs.

Discussion

Though subjects took significantly more time to produce the regular past tense forms of verb roots in the Rhyme condition than in the NonRhyme condition, the difference in past tense production times for the Rhyme and NonRhyme conditions is virtually eliminated for denominal verbs. Though this pattern of data (shown in Figure 1) is confounded with an effect of the frequencies of the nouns that the denominal verbs were derived from (as seen in Figures 2 and 3), a regression analysis shows that this confound cancels itself out, leaving us with more or less the original result: Though irregular past tense verbs affect the time it takes to produce the past tense forms of regular past tense verb roots, this effect virtually disappears for denominal verbs.

These results support the structure-in-time hypothesis by showing that the morphological structure of verbs directs the subsequent computations involved in computing their past tense forms: The past tense forms of regular verb roots are computed by a mechanism that is sensitive to the phonological properties of verbs, i.e., whether they rhyme with (or have sufficient phonological overlap with) irregular past tense verbs; the computation of the past tense forms of denominal verbs bypasses this mechanism. It is worth noting that this result supports a particularly strong version of the structure-in-time hypothesis: Not only is the effect of irregular past tense verbs on the time it takes to produce the past tense forms of verbs attenuated for denominal verbs relative to verb roots, it is virtually eliminated.

This demonstration of the structure-in-time effect supports the dual mechanism account of the production of regular past tense forms because the results are most straightforwardly accounted for by a theory in which the mechanisms that produce regular and irregular past tense forms are distinct. That is, if a verb is analyzed as having a verb root as its head, subsequent computation uses phonological information to determine whether or not the verb has an irregular past tense form, which leads to longer production times for regular verb roots that rhyme with irregular past tense verbs than for those that do not. On the other hand, if a verb is analyzed as a denominal verb (i.e., as not having a verb root as its head), subsequent computation does not use phonological

information in this way but simply computes the verb's regular past tense form by adding the "-ed" suffix to the verb stem, which results in no phonological effect of irregular past tense verbs on the time it takes to produce the regular past tense form of the verb.

On the other hand, the structure-in-time effect presents a challenge for the single mechanism account of the production of regular past tense forms because regular past tense formation does not have a privileged role in such an account. In fact, there is no explicit representation of the regular past tense rule, and no distinct mechanism responsible for just regular past tense formation in the single mechanism account. So it is not clear how the single mechanism account can distinguish what seems to be a categorical difference between verb roots and denominal verbs: Phonology affects the time it takes to produce the past tense forms of verb roots, but it does not affect the time it takes to produce the past tense forms of denominal verbs.

Experiment Three

There is another possible confound in Experiment 2: If it were the case that the particular irregular past tense verbs that the Rhyme condition verb root items rhymed with have an influence on the time it takes to produce the past tense forms of rhyming regular verbs, but that the particular irregular past tense verbs that the Rhyme condition denominal verb items rhymed with do not have such an influence, then one would also predict the pattern of results obtained in Experiment 2. If this is true, then the structure-in-time hypothesis may not be the source of the significant interaction effect in Experiment 2; the effect may be entirely due to a stronger effect exerted by the irregular past tense verbs that the Rhyme condition verb roots rhymed with than by the irregular past tense verbs that the Rhyme condition denominal verbs rhymed with.

One reason that such a difference in attraction strength of irregular past tense verbs might exist is that the effect of irregular past tense verbs on the time it takes to produce the past tense forms of regular past tense verbs is presumably due to a more general effect of the strength of phonological clusters of irregular past tense verbs, and a factor that determines the strength of such clusters includes the frequency of phonological features in such clusters (Ullman, 1993). Taking the number of rhyming irregular verb types as a rough estimate of the strength of the clusters of irregular past tense verbs, there is some reason to believe that the effect of irregular verbs on the Denominal/Rhyme

verbs might have been weaker than on the Root/Rhyme verbs. In particular, the five verb roots in the Rhyme condition from Experiment 2 that rhyme with more than one irregular past tense verb also typically rhyme with many irregular past tense verbs (i.e., *tend* rhymes with *bend/bent, spend/spent, send/sent, lend/lent,* and *rend/rent*; *heal* rhymes with *steal/stole, deal/dealt, feel/felt,* and *kneel/knelt*; *bake* rhymes with *make/made, awake/awoke, wake/woke, break/broke, take/took, mistake/mistook, forsake/forsook, shake/shook,* and *partake/partook*; *row* rhymes with *blow/blew, grow/grew, know/knew,* and *throw/threw*; *thaw* rhymes with *draw/drew* and *withdraw/withdrew*). On the other hand, the four denominal verbs in the Rhyme condition from Experiment 2 that rhyme with more than one irregular past tense verb only rhyme with two or three irregular past tense verbs (i.e., *sin* rhymes with *spin/spun* and *win/won*; *claw* rhymes with *draw/drew* and *withdraw/withdrew*; *hand* and *brand* rhyme with *stand/stood, withstand/withstood,* and *understand/understood*).

This experiment controls for this confound by testing whether the particular irregular past tense verbs that rhyme with the Rhyme condition denominal verbs from Experiment 2 give rise to the phonological effect demonstrated in Experiment 1. That is, the verb roots in the Rhyme condition in this experiment will rhyme with the Rhyme condition denominal items from Experiment 2. If there is an effect of the irregular past tense verbs that rhyme with these verb roots, then the weakness of the effect of this set of irregular past tense verbs cannot be the factor that led to the significant Denominal/Root x Rhyme/NonRhyme interaction in Experiment 2.

Method

Subjects. Fifteen native English-speaking adults were subjects in the experiment. They were paid for their participation.

Materials, Design and Procedure. This experiment was identical to Experiment 1 except that the nine pairs of items from that study that were not also in Experiment 2 were replaced with another nine pairs of verb root items. Of these, the Rhyme condition items rhymed with the Rhyme condition denominal items from Experiment 2. I will call these nine pairs of verb roots *the denominal-rhyming items*; I will call the nine pairs of verb roots from both Experiments 1 and 2 *the replication items.* The Rhyme/NonRhyme members of the nine pairs of denominal-rhyming verb root items were matched on length

and overall verb frequency using the frequency counts in the Associated Press lists and were all monosyllabic except for *command/punish*. None of these verbs were homophonous with any irregular past tense verbs. The nine pairs of denominal-rhyming verb root items are listed in Appendix C.

Results

For the nine pairs of replication items from Experiments 1 and 2, the mean response time for the Rhyme condition verb roots (923.34 msec) was greater than the mean response time for the NonRhyme condition verb roots (719.72 msec). This difference was significant in separate one-way ANOVAs with Rhyme/NonRhyme as the independent variable, one with Subjects as the random variable ($F1(1,14) = 18.19$, $p < .001$) and the other with Items as the random variable ($F2(1,8) = 37.71$, $p < .001$). This result replicates the effect found in Experiments 1 and 2 for this set of verbs. Subjects also made a low number of errors for the replication items, as they did in Experiments 1 and 2, though the pattern of errors was the opposite of that from Experiment 1: Subjects made one error in the NonRhyme condition and none in the Rhyme condition. So, though there might have been a speed-accuracy tradeoff, it is difficult to tell.

To see if this effect is the result of the frequency of the past tense forms of the verbs, these analyses were done for the three verb root items that had higher past tense frequencies in the Rhyme condition than in the NonRhyme condition. The mean response time for the three verb roots in the Rhyme condition (899.96 msec) was greater than the mean response time for the three verb roots in the NonRhyme condition (716.44 msec). This difference was significant in a one-way ANOVA with Subjects as the random variable ($F1(1,14) = 13.87$, $p < .005$). This difference was not significant in a one-way ANOVA with Items as the random variable ($F2(1,2) = 7.39$, $p = .11$), but this may have been due to the small number (i.e., three) of items in the analysis. Subjects made no errors in either the NonRhyme condition or the Rhyme condition for these three pairs of items. So, at least for the items that bias against finding the phonological effect of irregular past tense verbs, there was no speed-accuracy tradeoff.

For the nine pairs of denominal-rhyming verb root items, the mean response time for the Rhyme condition verb roots (886.78 msec) was greater than the mean response time for the NonRhyme condition verb roots (757.49 msec). This difference was significant in separate one-way ANOVAs with Rhyme/NonRhyme as the independent

variable, one with Subjects as the random variable ($F1(1,14) = 23.88$, $p < .001$) and one with Items as the random variable ($F2(1,8) = 17.84$, $p < .005$). Subjects made a total of four errors in the Rhyme condition but only one in the NonRhyme condition. Therefore, the results are not the effect of a speed-accuracy tradeoff.

To see if this effect is the result of the frequencies of the past tense forms of the verbs, these analyses were done for the seven verb root items that had higher past tense frequencies for the Rhyme condition than for the NonRhyme condition. The mean response time for the seven verb roots in the Rhyme condition (891.60 msec) was greater than the mean response time for the seven verb roots in the NonRhyme condition (773.84 msec). This difference was significant in separate one-way ANOVAs, one with Subjects as the random variable ($F1(1,14) = 16.33$, $p < .001$), and one with Items as the random variable ($F2(1,6) = 12.06$, $p < .02$). Subjects made three errors in the Rhyme condition but none in the NonRhyme condition.

Discussion

In this experiment, just as subjects took more time to produce the past tense forms of regular verb roots that rhyme with irregular past tense verbs than those that don't for the replication items, subjects took more time to produce the past tense forms of regular verb roots that rhyme with irregular past tense verbs than those that don't for the denominal-rhyming items. The significant Rhyme/NonRhyme difference for the denominal-rhyming items in this experiment shows that the phonological properties of the particular denominal verbs in Experiment 2 and the irregular past tense verbs and the irregular past tense verbs that they rhymed with are not likely to be the source of the structure-in-time effect in that experiment; if it were, one would have expected no difference between the Rhyme and NonRhyme conditions for the denominal-rhyming items in this experiment just as there was no such difference for the denominal verbs in Experiment 2.

Though the Rhyme/NonRhyme difference was significant both for the replication items and for the denominal-rhyming items, it is worth noting that the effect was smaller for the denominal-rhyming items (Rhyme minus NonRhyme = 129.20 msec) than for the replication items (Rhyme minus NonRhyme = 203.62 msec). The reason for this is unclear, though one distinct possibility is that the number of irregular past tense verbs (being a crude measure of the strength of a cluster of phonologically similar verbs -- see

Bybee & Moder, 1983; Prasada & Pinker, 1993; Ullman, 1993) does exert an effect on the time it takes to produce the past tense form of a rhyming regular verb root.[27] Nonetheless, this difference is not likely to be able to explain away the structure-in-time effect reported in Experiment 2. That is, though the Rhyme/NonRhyme difference was greater for the replication items in this experiment than for the same verb roots in Experiment 2 (203.62 msec - 183.81 msec = 19.81 msec), and it was greater for the denominal-rhyming items in this experiment than for the rhyming denominal verbs in Experiment 2 (129.29 msec - 4.31 msec = 124.98 msec),[28] this difference is much greater in the latter case. If this trend towards a larger Rhyme/NonRhyme difference in this experiment relative to Experiment 2 had the same source for both the replication items and the denominal-rhyming items, one would expect this trend to be similar in the two cases. But they are not: The difference is almost an order of magnitude greater in the latter case.

General Discussion

These experiments show two things. First, irregular past tense verbs exert an influence on the time it takes to produce the past tense forms of regular past tense verb roots: It takes longer to produce that past tense form of a regular past tense verb root if it rhymes with an irregular past tense verb than if it does not. This is hardly surprising, and is consistent with a number of possibilities, including both the single mechanism account and the dual mechanism account. Second, this effect that irregular past tense verbs have on the time it takes to produce the regular past tense forms of verb roots virtually disappears for denominal verbs, as a particularly strong version of the structure-in-time hypothesis predicts.

A simple and straightforward account of the structure-in-time effect comes from the dual mechanism account. Consider how the computation of the past tense form of a regular past tense verb might proceed under such an account: First, the morphological structure of a verb is computed. If the verb is a denominal verb (i.e., does not have a verb

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[27]Another possibility is that the greater Rhyme/NonRhyme difference for the replication items than for the denominal-rhyming items is related to the fact that there may have been a slight speed-accuracy tradeoff for the replication items, but none for the denominal-rhyming items.

[28]Or 129.29 msec - (-2.54 msec) = 131.83 msec by the estimate from the regression equation

root as its head), then the regular past tense formation mechanism (which is not sensitive to the phonology of the verb being inflected) adds the regular suffix to the stem; but if the verb has a verb root as its head, then a lexical lookup mechanism that uses phonological information to determine whether it could possibly be an irregular past tense form (given the phonological structure of the irregular past tense verbs in the language) is invoked. In the latter case, if a regular verb root does not rhyme with an irregular past tense verb, then the regular past tense mechanism adds the "-ed" suffix to the verb stem; but if a regular verb root does rhyme with an irregular past tense verb, then this phonological similarity to irregular past tense verbs is enough to delay the mechanism that directs the computation of its past tense form to the regular past tense formation mechanism. This flow of information for the online production of past tense forms is shown in Figure 4.

Insert Figure 4 about here

It is significant that the flow of information diagramed in Figure 4 reflects the inherent design of the formal linguistic account of the past tense of verbs, which goes as follows: The default regular past tense rule, which is distinct from the irregular past tense mechanisms, applies to a verb as a variable whenever a verb is determined not to have an irregular past tense root in head position. This is categorically true for all denominal verbs; for verb roots, it has to be determined based on the basis of lexically specific information, including phonological properties of the verb root. As noted in the introduction, it did not have to be the case that the online past tense production mechanisms reflect this knowledge directly. Interestingly, they do, which speaks not only to the question of how past tense forms are computed online, but to the issues of the psychological reality of linguistic representations and how linguistic knowledge is instantiated in performance systems.

Modular Connectionist Architectures & the Dual Mechanism Account

Jacobs, Jordan and Barto (1991) showed that modular connectionist architectures lead to better learning by using separate networks to handle the distinct components of a learning problem that have distinct computational demands. Such modular networks use the properties of the input that indicate the nature of the computation required to shunt the subsequent computation to the appropriate subnetwork, which may be innately designed to handle certain types of computations better than others. Prasada and Pinker (1993) suggested that this type of modular architecture might be better suited for inflectional morphology given the different computational demands of regular and irregular inflection than the McClelland and Rumelhart (1986) model and the class of undifferentiated models that followed it. That is, if the modular architectures that Jacobs, et al. (1991) developed could use the properties of the input to shunt the input to separate networks for regular and irregular inflection (possibly with different architectures for the lexically-based nature of irregular inflection and the rule-based nature of regular inflection) such a network might instantiate the inflectional theories that linguists have developed, and provide the basis for accounting for further behavioral data not well-accounted for by strict rule-based theories (e.g., effects of frequency and phonological similarity structure).

It is easy to see how such a modular network might be able to account for the effect of irregular past tense verbs on the time it takes to produce the regular past tense form of verb roots. Assuming that the gating network that shunts subsequent computation to separate subnetworks uses phonological information to determine which subnetwork is appropriate for the task of computing the past tense form of a verb, regular and irregular past tense verbs whose stems share many phonological properties will share many input-output connections. This could be translated into longer times to decide to send such regular past tense verbs to the regular past tense formation network, based on this interference from the irregular past tense verbs that the network was trained on, than for regular past tense verbs whose stems do not share many phonological properties with irregular past tense verbs.

The problem for this simple story comes from denominal verbs: If the gating network uses phonological information to determine which past tense mechanism a verb

root should be sent to, then one would expect the gating network to use phonological information to determine which past tense mechanism a denominal verb should be sent to at least to some extent. But Experiment 2 shows that the online computation of the past tense forms of verbs is affected by the phonological properties of a verb stem *only if* the verb has a verb root as its head. So before the computation reaches the gating network, some mechanism must direct the computation of exocentric stems directly to the regular past tense mechanism, bypassing the gating network altogether. This addition to the modular gating network suggested by Prasada and Pinker (1993) could account for the effects discovered in this paper, and mimicks the flow of information outlined in Figure 4, and thus implements the linguistic rule system that accounts for the categorical regularization of stems that do not have roots as their heads.

Implications for Language Acquisition

These results have implications for language acquisition as well, which follow from one basic result: The flow of information in the online computation of past tense forms reflects the knowledge that underlies the inflectional system. There is some question about how the system underlying the knowledge that denominal verbs have regular past tense forms is acquired. One answer proposed by Kim, et al. (in press), based on how children inflect exocentric stems compared to word roots and an analysis of the linguistic input available to children at this age, is that it is not learned, but is inherent to the design of the inflectional system. Though this may be the case, it cannot be the entire acquisition story because the particular morphophonological form of regular past tense inflection still has to be learned on a language-by-language basis. The question is how does the learner determine which inflection is the regular default rule? This is a particularly interesting problem because some obvious possibilities cannot be the only responsible factors. That is, frequency of a particular inflectional form is not sufficient because default regular inflection can have low frequency in some languages. In fact, in German, the default regular plural *-s* is the *least* frequent plural morpheme (Marcus, et al., 1993). Explicit instruction is not likely to be the only responsible factor because this is not the type of thing that is explicitly taught to children about language. Furthermore, Kim, et al. (in press) show that children are sensitive to the effect of morphological structure on the choice of inflection before they enter school. So though both of these types of information might play some role in the acquisition of inflectional morphology,

they are not sufficient.

Another possibility, which would provide the learner with decisive evidence about which inflection in a language is the default regular rule for a given inflection, is that the learner might wait to hear which inflected form is used for stems without a root in head position. Because no inflection other than the regular, default inflection could have been used for such stems, the inflected form that is used for such stems *must* be the regularly inflected form. Interestingly, such an account of the acquisition of inflection is precisely what one gets if one turns the sketch of a dual mechanism account in Figure 4 into a learning mechanism. Consider using the modular connectionist architecture discussed above (Jacob, et al., 1991) as the learning mechanism (i.e., if a mechanism for morphological analysis, a mechanism to direct the flow of computation depending on the output of that analysis, and a gating network structured as in Figure 4 were the initial state of the language acquisition device for the past tense system):[29] If the verb is a denominal verb, then its past tense form is computed by the regular past tense formation mechanism, so the learner determines which morphophonological form is the regular past tense inflection by noticing what the past tense forms of denominal verbs are. If the verb is a verb root, then the phonological gating network would be used to learn which past tense formation mechanism is the correct one for that particular verb; this training will learn to shunt verbs to the appropriate subnetwork using various information, including phonological properties of verb stems. The end state of acquisition would be a system that accounts for the results of the experiments reported in this paper, and has acquired the default regular past tense rule.

So not only can the dual mechanism account explain the structure-in-time effect reported in this paper in a simple and straightforward fashion, but it can also provide a learning mechanism that can learn the regular default past tense form in any particular language in such a way that highlights the non-accidental nature of the regularization of headless stems. This doesn't show that children actually learn these properties of past tense inflection in this way, but the computational architecture needed in order to use such a learning strategy is independently needed to account for the processing results reported in this paper. Furthermore, this basic modular architecture is consistent with a

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[29]Whether or not such modular connectionist architectures could be used to implement past tense inflection in this way remains to be seen.

wide range of phenomena that implicate a categorical difference between regular and irregular inflection (see Pinker & Prince, 1988; Kim, et al., 1991; Marcus, et al., 1992; Prasada, et al., 1990; Xu & Pinker, 1992; Senghas, et al., 1992; Marcus, et al., 1993; Prasada & Pinker, 1993; Ullman, 1993; Kim, et al., in press).

Non-Modular Networks & the Single Mechanism Account

An immediate problem for the Rumelhart and McClelland (1986) model of the acquisition and use of the past tense of English is that it cannot handle the fact that homophonous verbs can have different past tense forms because the input representations of verbs include only phonological information in their model. Subsequent single-network modelers, such as MacWhinney and Leinbach (1991), suggested adding semantic features to the input representation to alleviate this problem. That is, semantic features could be used, along with phonological features, to distinguish homophonous verbs and, thus, could allow different past tense forms to be computed for homophonous verbs by a homogeneous network. For the purposes of the following discussion, it is worth noting that some representational device in the input layer of a homogenous network is required in order to distinguish homophonous verbs with different past tense forms; this follows from logic. This is particularly important in the context of denominal verbs because the process of denominalization provides a productive means of generating such cases of homophony, as noted in the Introduction. The relevance of this point to this paper is that such a non-phonological difference in the input representations of denominal verbs and verb roots in a homogeneous network is also necessary to account for the results reported in this paper. That it, there is a clear difference between denominal verbs and verb roots in the experiments reported in this paper: Denominal verbs show no Rhyme/NonRhyme difference, but verb roots show a large Rhyme/NonRhyme difference. Because the denominal verbs from Experiment 2 and the verb roots from Experiment 3 are maximally similar phonologically, the difference between them cannot be captured by a homogeneous network that employs nothing but phonological representations *in principle*. So some non-phonological input difference between denominal verbs and verb roots is necessary in order to account for the effects reported in this paper. The questions facing single-network models are what the nature of the representational difference is, how it is encoded in the input representation, and how it interacts with the environment during the learning phase of the network.

General problems for non-phonological input nodes

A simple way to distinguish denominal verbs and verb roots in the input representation is to add a "denominal" node to the input vector of a network. There are two problems with such an account. First, adding a "denominal" node to the input representation of a homogeneous network is an ad hoc solution to the homophony problem and is stipulative as an account for the results reported in this paper: A "denominal" input node is chosen simply because it works, without regard for what it means to be a denominal verb or how "denominalness" is related to deeper principles. This is especially relevant because the formal linguistic account of the fact that denominal verbs have regular past tense forms is not ad hoc in this way: It follows without stipulation from an account of how words are interpreted, as discussed in the Introduction. But in a homogeneous network, positing a denominal input node is an unilluminating implementation of a descriptive fact for which the formal linguistic account provides an explanation.

In fact, this problem is more general. For instance, the choice of semantic nodes used to solve the homophony problem in the MacWhinney and Leinbach (1991) model is ad hoc in the same way -- no motivation was given for choosing a particular set of semantic input nodes and no account was given for how they might be related to other phenomena.[30] I will not discuss the problems that employing semantic nodes in the way that MacWhinney and Leinbach use them in detail here, but refer the reader to the discussion of these problems in Kim, et al. (1991) and Kim, et al. (in press). This is not to say that there is no independently motivated reason to choose some set of non-phonological input nodes that would distinguish denominal verbs from verbs with verb roots as their heads, but this problem has not been considered seriously and, consequently, no theory that would motivate a set of non-phonological input units has been proposed.

Second, adding a "denominal" node (or any set of non-phonological nodes) to the input representation of a homogeneous network implicitly assumes that the fact that

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[30]MacWhinney and Leinbach (1991) also fail to demonstrate that their network generalizes properly when such representations are added to the vector of input nodes.

denominal verbs have regular past tense forms is an accidental property of some particular languages. That is, the "denominal" input node is not innately linked to the regular past tense inflection. In fact, prewiring some set of input nodes to regular past tense inflection would be against the spirit of a homogeneous network in which no qualitative difference between regular and irregular past tense forms is represented. That is, innately linking the "denominal" input node to "regular" past tense formation implicates a qualitative difference between regular and irregular past tense inflection (i.e., one type of inflection is innately linked to the denominal input node and another type of inflection is not). Indeed, doing so seems to require having a predesignated set of output nodes that have the properties of the regular past tense for the denominal input node to be connected to. Such an approach approximates, or may be equivalent to, the modular network model discussed above. Barring any such innate links of this sort in homogeneous networks, there is no reason in such models that denominal verbs have to have *regular* past tense forms:[31] Such a representational scheme only allows for the possibility that denominal verbs could have different past tense forms than homophonous verb roots; because the mapping between input and output nodes is completely driven by environmental input in a homogeneous network, it is completely accidental that denominal verbs categorically have regular past tense forms (i.e., that only verb roots can have irregular past tense forms). In fact, such models are consistent with, and, in lieu of any additional constraints on how headless stems are inflected, predict the existence of languages that inflect headless stems with irregular inflection, regular inflection, or any mixture of the two.

But if one considers the range of cases in which stems without a head categorically have regular inflected forms, the link between headedness and regular inflection seems to be anything but accidental. As mentioned in the Introduction, regular inflection is applied quite generally to stems that do not have roots as their heads. So simply adding non-phonological input nodes to a homogeneous network misses the point of the generalization discovered by Mencken (1936) and Kiparsky (1982): There is something special about headless stems and how they are related to regular and irregular inflectional mechanisms.

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[31]"Regular" is defined by other criteria as well, such as the inflection which applies to stems that do not follow the sound pattern of the language.

The modelling challenge for non-modular networks

These problems notwithstanding, consider a homogeneous network with non-phonological as well as phonological input nodes. Such a model could give rise to the effects found in this paper. Consider how such a model would have to be wired: The connections between the input representations of irregular past tense verbs and the output representations of their past tense forms have to be strong enough to generate the irregular past tense form given the irregular past tense verb as input. The non-phonological input nodes of homophonous denominal verbs would have to be able to inhibit those output nodes that are not also the output nodes of the verb's regular past tense form. Because there is usually a lot of overlap between irregular verbs and their past tense forms, and regular past tense forms include the verb stems that they are based on, only a relatively small set of features will have to be inhibited by the denominal input node. Furthermore, the regular past tense set of endings will have to be activated by the denominal input node. But this is not sufficient to account for the structure-in-time effect reported in this paper; In order for the model to produce these effects, the non-phonological input nodes for denominal verbs have to be able to completely nullify the effect of the phonological input nodes on the output nodes specific to the irregular past tense form. Though it has not been shown that a model could be hand-wired to perform like this, it is likely that such a wiring could be found. The challenge is for the homogeneous network to arrive at such a wiring through interaction with the linguistic environment available to the learner. I have no evidence about whether a homogeneous network could succeed at this task, but it is a challenge for proponents of homogeneous models of inflection.

One reason to believe that homogeneous networks may not be able to succeed at such a task is that the success of such a network depends on the statistical properties of the linguistic input. Though regular past tense verbs are far more frequent than irregular past tense verbs in English, this is not the case generally. In fact, as mentioned in the Introduction, Marcus, et al. (1993) showed that headless stems are regularized even in cases in which regular inflection is the *least* frequent of a set of possible inflections. The same is true of the broken plural in Arabic (McCarthy & Prince, 1990). Though there are no relevant reaction time studies to my knowledge that test the structure-in-time

hypotheses in these languages, the challenge applies as well to the facts reported in Marcus, et al. (1993) and in McCarthy & Prince (1990): The rule-like properties of regular inflection have to be able to be learned by a homogeneous network even when they constitute a minority of inflected forms in the linguistic input.

On the other hand, the dual mechanism account of the acquisition of regular inflection proposed above does not suffer from this criticism because the rule-like properties of inflection do not depend solely on the statistical properties of the linguistic input -- the dual mechanism account of the phenomena reported in this paper can acquire the rule-like properties of regular inflection even in this circumstance.

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APPENDIX A. STIMULI FROM EXPERIMENT ONE

A.1 Verbs that are only in Experiment One

NonRhyme	Rhyme	Rhyming Irregulars
toss	strand	stand, withstand, understand
hug	heed	bleed, breed, feed, lead, mislead, read, speed, plead
weld	skim	swim
vex	scoot	shoot
prowl	scold	hold, behold
poke	shun	run
drip	mow	blow, grow, know, throw
dump	owe	blow, grow, know, throw
flap	stow	blow, grow, know, throw

A.2 Verbs that are in Experiments One, Two and Three

NonRhyme	Rhyme	Rhyming Irregulars
wilt	row	blow, grow, know, throw
carve	stun	run
roll	tend	bend, send, spend, lend, rend
punch	heal	steal, feel, deal, kneel
pause	bake	wake, make, awake, break, take, mistake, forsake, shake, partake
suck	smear	hear
whirl	thaw	draw, withdraw
squash	sneeze	freeze
mince	wheeze	freeze

APPENDIX B. STIMULI FROM EXPERIMENT TWO

(The first context in each quadruple is Denominal/NonRhyme; the second is Denominal/Rhyme, the third is Root/NonRhyme; the fourth is Root/Rhyme.)

1. milk/spike/wilt/row

The girl at the farm was very unhappy about having to milk the cows.
But she was the only one who was well enough to do the chores.

The young woman hated the current fashion so she decided to spike her hair.
She liked it so much that she convinced her friends to do it too.

The gardener at the estate makes sure that the flowers don't wilt at all.
He's especially proud of how well he takes care of the flower garden.

The skinny student didn't know if he was strong enough to row the boat.
He decided to try to get across the river and he barely made it.

2. cap/brand/carve/stun

The rich people in this country cap their teeth as a sign of success.
People's teeth are so bad here that it does make a difference.

The dairy farmers in this town brand their cows in order to identify them.
There are so few farms around here that it doesn't make sense.

The Navajo indians in this area carve ornate wood figures with sharp blades.
They are so beautiful that people are selling them across the country.

The fortune tellers in this city stun the public by being right so often.
Many people are beginning to take that stuff pretty seriously around here.

3. fish/hand/roll/tend

The townspeople fish for salmon in the fall when they swim upstream to spawn.
This isn't prohibited by law, though it probably should be.

The students hand their papers in on time when their grade depends on it.
The smart teachers always take points off for late homework.

The children roll a big ball around when they are at the daycare center.
The older, more coordinated children play catch during playtime.

The boys tend to get into big trouble when their parents leave them alone.
Fortunately, their parents are usually around to control them.

4. whip/loot/punch/heal

The captors will have to whip the prisoners for their failed escape attempt.
They don't enjoy their job, but it's a good deterrent.

The thieves will try to loot the jewelry store before they leave town.
They won't waste their time on stores with cheaper merchandise.

The boxer will want to punch his opponent quickly before he's too tired.
He wasted a lot of energy early in the fight.

The cast will help to heal the boy's arm by keeping it immobile.
Unfortunately the cast is very uncomfortable in this hot weather.

5. stack/root/pause/bake

The disorganized student tried very hard to stack his papers in neat piles.
But they always end up in heaps on the floor.

The jazz band tried so hard to root their sound in zydeco music.

The result was interesting, but not very successful commercially.

The news anchorperson tried very hard to pause between the two news stories.
But he was nervous, and the two stories ran together.

The culinary student wanted so badly to bake an award winning French souffle.
At the school competition, his recipe came in second place.

6. bus/steam/suck/smear

The governor knew that he had to bus the minority children across the city.
He was nervous because there was a lot of resistance to the court's decision.

The chef knew that he had to steam the mussels for about fifteen minutes.
They were overdone because his assistant forgot to take them off of the stove.

The repairman knew he had to suck on the hose to start the siphon.
But he was anxious because he got a mouthful of gasoline the last time.

The artist decided that he wanted to smear red paint on his charcoal sketch.
This delighted his admirers because it added a lot of color to his work.

7. cart/sin/whirl/thaw

The fireman asked the children to cart sand over to the fire in wagons.
He used it to keep the fire from spreading further.

The priest told people not to sin if they wanted to go to heaven.
He got so aggressive that he started putting people off.

The nasty little boy tried to whirl the black cat around by its tail.
The boy started crying when the cat scratched his face.

The hungry lawyer didn't try to thaw the frozen T-bone steak out for dinner.

It takes too long, so he ordered a large pizza.

8. wax/claw/squash/sneeze

The janitors wax the floor every other week.
It is a real nuisance when you're trying to work.

The kittens claw at anything made of fabric.
They managed to destroy my new sweater in twenty minutes.

The children squash little bugs on the sidewalk.
I've told them not to, but they just don't listen.

The boys sneeze whenever there's a dog around.
They are pretty much allergic to all animals with fur.

9. cage/spear/mince/wheeze

Zookeepers sometimes cage apes in the zoo.
But it's better to let them have more space to move.

Hunters often spear wild boar from trees.
It's unsafe to hunt them any other way without a gun.

Chefs seldom mince ginger in their recipes.
Ginger is more flavorful if you slice it into thin strips.

Marathoners never wheeze when they run sprints.
But sprinters have a lot of trouble breathing after a marathon.

APPENDIX C. DENOMINAL-RHYMING ITEMS FROM EXPERIMENT THREE

NonRhyme	Rhyme	Rhyming Denominals	Rhyming Rhyming Irregulars[32]
twist	hike	spike	strike
starve	strand	brand	stand, withstand, understand
punish	command	hand	stand, withstand, understand
snip	scoot	loot	shoot
whack	hoot	root	shoot
wipe	scream	steam	dream
hop	grin	sin	win, spin
smudge	gnaw	claw	draw, withdraw
wage	cheer	spear	hear

[32]These are also the irregular past tense verbs that rhyme with the Denominal/Rhyme condition verbs from Experiment 2.

Table 1

Reaction Times from Experiment 2

	Verb Roots	Denominal Verbs
Rhyme	919.18	803.08
NonRhyme	735.37	798.77
Rhyme minus NonRhyme	183.81	4.31

Table 2

Reaction Times from Experiment 2 (excluding *cart/sin/whirl/thaw*)

	Verb Roots	Denominal Verbs
Rhyme	925.08	797.67
NonRhyme	745.61	800.30
Rhyme minus NonRhyme	179.47	-2.63

Table 3

Reaction Times from Experiment 2

(For the Three Items with a Higher Noun Frequency for Denominal/Rhyme Verbs than for their Denominal/NonRhyme Counterparts)

	Verb Roots	Denominal Verbs
Rhyme (high noun frequency)	911.39	884.50
NonRhyme (low noun frequency)	698.04	982.32
Rhyme minus NonRhyme	213.35	-97.82

Table 4

Reaction Times from Experiment 2

(For the Six Items with a Lower Noun Frequency for

Denominal/Rhyme Verbs than for their Denominal/NonRhyme Counterparts)

	Verb Roots	Denominal Verbs
Rhyme (low noun frequency)	924.58	767.33
NonRhyme (high noun frequency)	751.62	717.10
Rhyme minus NonRhyme	172.96	50.23

Figure Captions

Figure 1. Mean response times in Rhyme and NonRhyme conditions for verb roots and denominal verbs in Experiment 2.

Figure 2. Mean response times in Rhyme and NonRhyme conditions for verb roots and denominal verbs Experiment 2 (for the three items with a lower Noun frequency for Denominal/Rhyme verbs than for their Denominal/NonRhyme counterparts).

Figure 3. Mean response times in Rhyme and NonRhyme conditions for verb roots and denominal verbs Experiment 2 (For the six items with a higher Noun frequency for Denominal/Rhyme verbs than for their Denominal/NonRhyme counterparts).

Figure 4. Flow of information in a version of the dual mechanism account.

Figure 1.

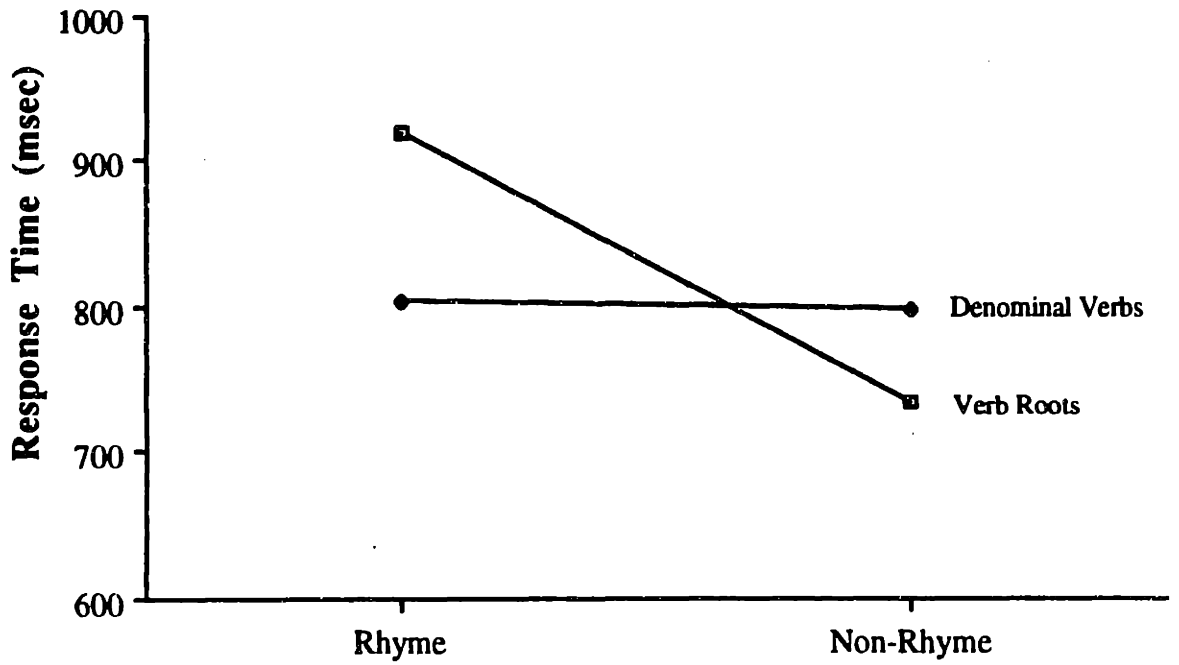

1000
900
800
700
600
Response Time (msec)
Denominal Verbs
Verb Roots
Rhyme
Non-Rhyme

Figure 2.

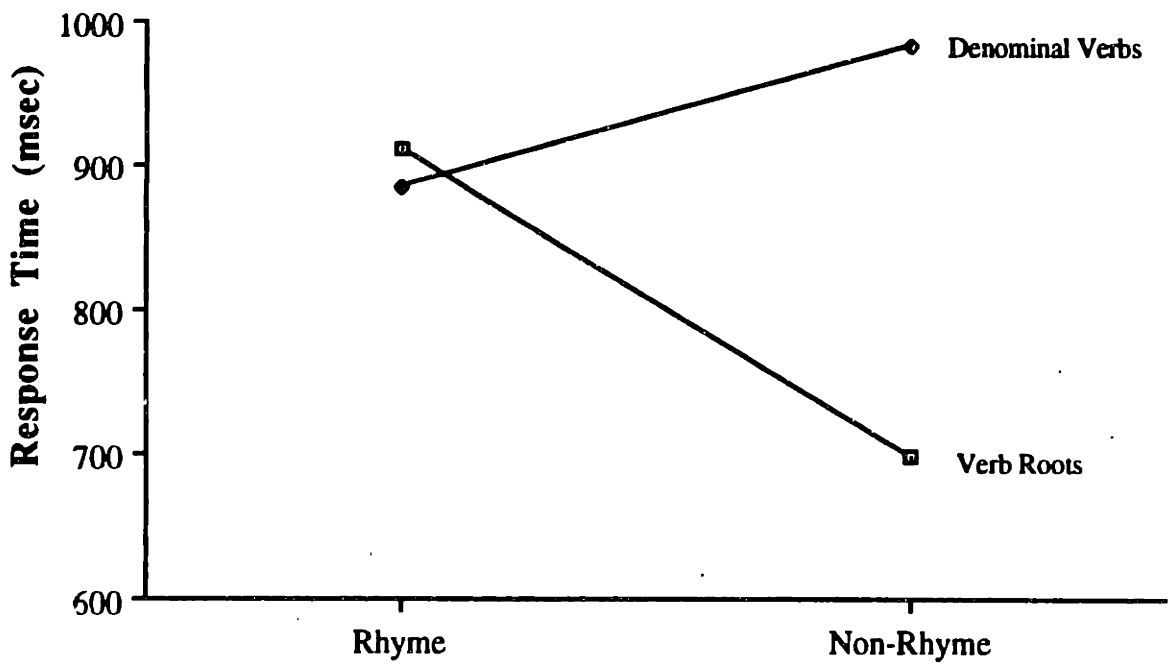

1000
900
800
700
600
Response Time (msec)
Denominal Verbs
Verb Roots
Rhyme
Non-Rhyme

Figure 3.

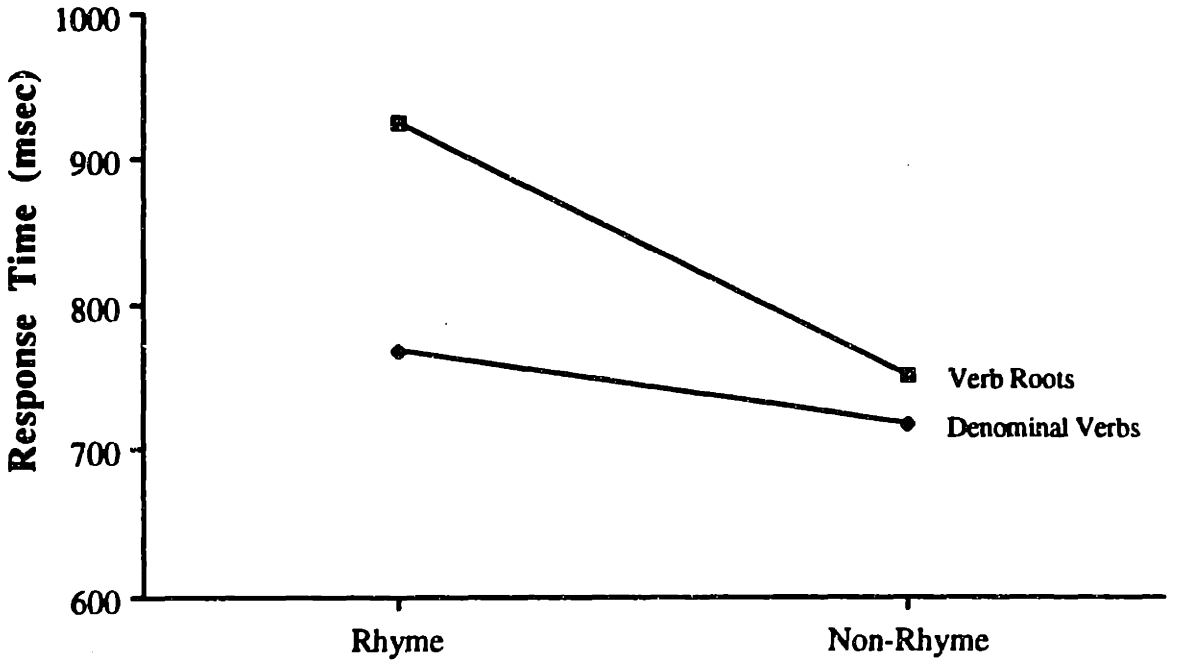
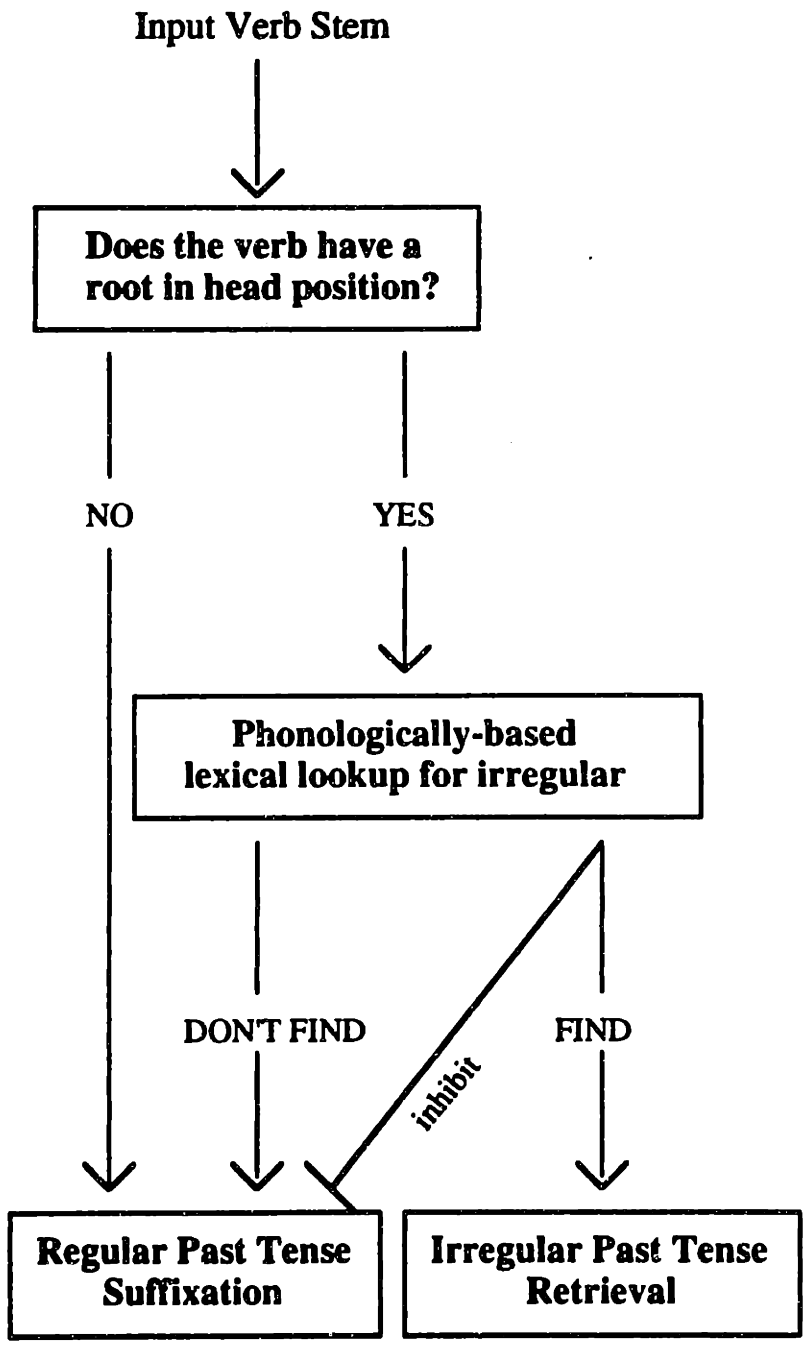

1000
900
800
700
600
Response Time (msec)
Rhyme
Non-Rhyme
Verb Roots
Denominal Verbs

Figure 4.


Input Verb Stem
Does the verb have a root in head position?
NO
YES
Phonologically-based lexical lookup for irregular
DON'T FIND
FIND
inhibit
Regular Past Tense Suffixation
Irregular Past Tense Retrieval