*Word Games and Syllable Structure**

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KEY WORDS

onset

prosodic morphology

rhyme

syllable

word games

ABSTRACT

The internal structure of the syllable has been a matter of long-standing debate. Some theories propose a highly articulated tree structure whose topmost constituents are the onset and the rhyme. However, much recent work in phonological theory has adopted a flatter model in which neither the onset nor the rhyme constitutes a constituent.

Experiments using the novel word game paradigm developed in Treiman (1983) have been interpreted as supporting the onset-rhyme model. Here we present new results using this paradigm. Subjects learned to insert infixes into simple monosyllabic words, and then extended the infixation to more complex forms including longer words with variable stress placement. The results are interpreted in the light of findings about morphophonemic processes occurring in natural language. Our model draws on the concept of template mapping, adapted from the literature on prosodic morphology. The patterns observed in the data are better modeled by mapping onto output templates than by any derivational rule referring to onset-rhyme constituency. Though the output templates do include prosodic detail, the level of detail available in flat models of the syllable is sufficient to explain the results. A critical appraisal of these results in relation to other results in the literature leads us to reject the onset-rhyme model.

INTRODUCTION

In the long history of research on the syllable, there has been a persistent tension between models of the syllable with a highly articulated tree structure, and models in which the structure is considerably flatter. The syllabic structure for English presented in Fudge (1969), and repeated in (1) exemplifies the first approach:

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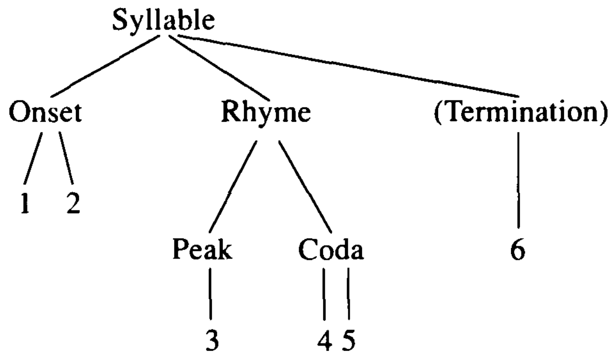
(1)



As can be seen in (1), the topmost split in the hierarchical structure is between the onset and the rhyme (with an optional termination); further subdivisions within the onset and the rhyme provide for the various combinations of segments which are permissible in complex cases. Related models are adopted by Goldsmith (1990), Selkirk (1982), Kiparsky (1979), and many other authors.

Other authors, including Clements and Keyser (1983) and Hyman (1985), have proposed flatter structures for the syllable. In recent work in generative phonology, one particular flatter model of the syllable has gained considerable currency. This is the so-called moraic syllable, as proposed in Hyman (1985), Hayes (1989) and McCarthy and Prince (1990a, b). The mora is a unit of metrical weight or length, with light syllables having a single mora and heavy syllables having two morae. Apart from the possible branching of the syllable into two morae, no further internal structure is posited. For example, according to Hayes the first syllable of "trample" and the monosyllable "tree" would have representations as shown in (2):

(2)

Note that in (2), neither the onset nor the rhyme appears as a constituent. Nonetheless, the onset consonants have a different status from the moraic consonants because they are not dominated by any mora, but rather directly dominated by the syllable node. Hence, (2) does draw a difference between onset consonants and coda consonants which can be used to model (for example) why onset consonants exhibit different allophony from coda consonants and why they fail to interact with coda consonants in speech errors.

Variants of the moraic model have been widely accepted both because the moraic syllable supports an attractive theory of stress and compensatory lengthening and because many of the phonotactic arguments for a highly articulated syllable structure have been shown to be spurious. A far from exhaustive list of work in generative linguistics which presupposes the moraic syllable includes: Archangeli (1991), Beckman (in press), Hayes (1989; 1995), Ito (1990), Ito and Mester (in press), Kager (1993), Lamontagne (1993), McCarthy and Prince (1986 ms; 1990a, b) and Prince (1990).

However, in the course of adopting the moraic model, generative linguists have not addressed the psycholinguistic evidence which has been interpreted as supporting the onset/rhyme model. This evidence includes patterns of speech errors (MacKay, 1972; Stemberger, 1983; Fowler, 1987; Treiman & Danis, 1988); and experiments using novel word games of various types (Treiman, 1983, 1986, 1988; Fowler, Treiman, & Gross, 1993; Treiman, Fowler, Gross, Berch, & Weatherston, 1995).

Such evidence now stands as the primary support for the onset/rhyme model. Therefore, it is necessary to reexamine the assumptions made in interpreting the various experimental findings to ascertain whether they support the onset/rhyme distinction per se, or whether they merely support some more general notion of prosodic position which can equally well be expressed using flatter syllabic models. This re-evaluation is particularly relevant in light of the fact that developments in phonological theory, reviewed in the next section, have substantially modified our conception of phonological constituency and its consequences.

Novel language games were introduced as evidence about syllable structure in Treiman's (1983) paper. Her design used a concept generalization task to demonstrate that the preferred splitting point in monosyllabic words is at the division between the classical onset and the classical rhyme. This result was interpreted both by Treiman and by subsequent authors as supporting the onset and rhyme as phonological constituents; see, for example, the review of syllable structure in Levelt (1989).

The series of experiments reported here sought both to replicate Treiman's main finding, and to extend the paradigm to more complex materials in order to clarify the theoretical interpretation. Insertion of VC and C infixes into both monosyllabic base forms and polysyllabic base forms with differing stress patterns was examined. The scrutiny and control of the output phonotactics was more thorough than in Treiman (1983) or the subsequent papers, such as Fowler et al. (1993) and Treiman et al. (1995).

There were two main findings. First, confirming the original findings, complex initial onsets were preserved far more than they were split. However, the percentage of splits is substantially increased if the result of splitting the onset is phonotactically impeccable. Second, the onset/rhyme division was found to be neither necessary nor sufficient to explain the pattern of responses observed for more complex materials. However, the responses were found to reflect detailed sensitivity to prosodic position, broadly confirming psycholinguistic results from Fromkin (1973) to Shattuck-Hufnagel (1985, 1986) and Fowler et al. (1993).

We propose to model this sensitivity by building on a body of work in prosodic morphology which uses the concept of template-mapping. Specifically, we propose that subjects acquired maximally detailed prosodic templates for outputs with the infixes they were taught in the word game experiments. Though these templates are very detailed, representing in effect minimal generalizations over the outputs encountered in the training, they do not require a highly articulated syllable structure but can equally well use the moraic model or indeed almost any flat model. When extending the word games to more complex new materials, the subjects pick the outcome which best matches the prosodic template for the infix. The weighting of factors in computing a best match is variable amongst subjects, but broadly reflects phonotactic regularities in the language. We also note that the representation of the prosodic templates for the games can be

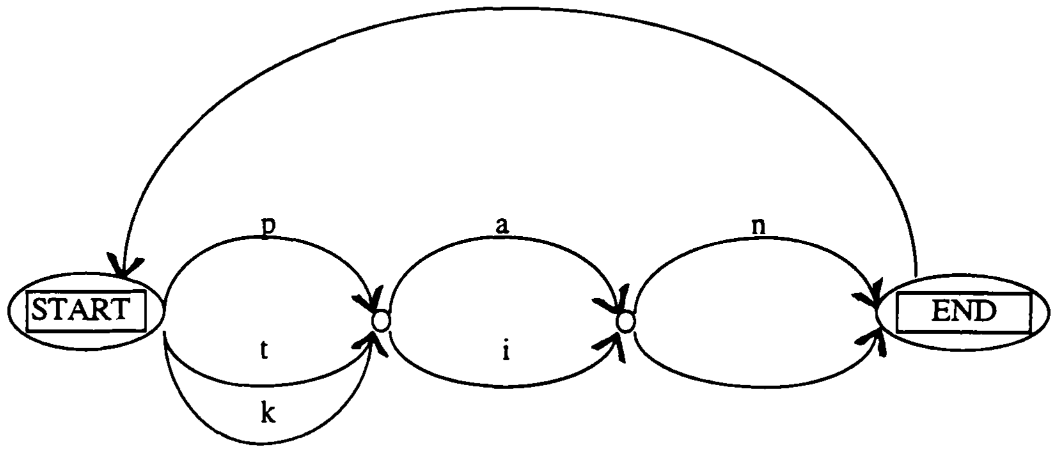


Fig. 1

Example of a transition network for a simple finite-state grammar.

incrementally modified by examples encountered in the course of the experiments. This finding, which is hardly unexpected, has important consequences for the theory of lexical representation, tending to support theories such as Declarative Phonology in which lexical entries and rules or constraints are represented in the same way.

As background and motivation for our experiments, we review the relevant phonological and experimental literature in the next two sections. Then we present the experiments and their results. The final section develops the proposal just sketched and locates the model with respect to current topics of debate in the field.

THEORY OF THE SYLLABLE AND OF PROSODIC CONSTITUENCY

Constituency

The theory of syllable structure is embedded in the theory of prosodic constituency, which is an instantiation in the domain of language sound structure of the general theory of constituency provided by formal language theory. The Chomsky hierarchy provides a characterization of the mathematical complexity of different formal languages. Complexity is defined in terms of the types of interdependencies which obtain amongst the elements of terminal strings in a language, which determine what type of grammar or parser is needed to generate or recognize all and only the strings which are well-formed in that language. The exposition which follows provides a synopsis of results covered in any introductory formal language theory textbook, such as Harrison (1978).

The least complex type of language in the Chomsky hierarchy is that characterizable by a finite-state grammar. A finite state grammar can be graphically represented using a network, as in Fig.1. In this grammar, all dependencies are purely sequential.

A well-formed output can be created by tracing through the arcs in any order from the start state to the end state. This particular grammar generates the sequences /pa/, /pan/, /ta/, /tan/, /ka/, /kan/, /pi/, /pin/, /ti/, /tin/, /ki/, /kin/, as well as combinations of these basic sequences of any length and in any order, for example /pitankinka/ or /tinkipanki/.

Statistical studies of phonotactics have identified many regularities which are purely sequential. For example, a much-studied phonotactic principle of Arabic has the result that verbal roots containing two consonants in a row at the same place of articulation are very scarce (see McCarthy, 1988; McCarthy, 1994; Pierrehumbert, 1993; the principle is known as OCP-Place, or the Obligatory Contour Principle for place of articulation). Because the verbal roots in question appear in many different inflected and derived forms, the consonants in question occupy various positions in the syllable. Hence, the phonotactic principle cannot be stated with respect to syllabic positions, but must be stated over the bare sequence of consonants.

A statistical study of the English dictionary by Lamontagne (1993) shows that English has a constraint against obstruent clusters containing one voiced obstruent. This constraint applies to any obstruent sequence within a monomorphemic word, regardless of syllabification. Words such as "rafter" and "actor" are well-formed in English, but obstruent clusters containing a voiced obstruent only occur freely when the obstruents are separated by a word boundary, as in "birdfeed" or "spicebush". Similarly, there are many words containing the sequence /sp/, /st/, /sk/, such as "spot" "fast" "pesky"; however the clusters /sb/, /sd/, /sg/ are not found within monomorphemic words regardless of syllabification.

The same sort of observation may be made about sequences containing a labial stop followed by /w/ (/pw/, /bw/). The 70,000 word on-line Collins English Dictionary (distributed through the ACL Data Collection Initiative) contains no instances of /pw/ whatsoever except in compounds and recent borrowings; there is only one noncompound word with /bw/, which is a borrowing ("Ojibwa"). That is, even the possibility of syllabifying the /p/ or /b/ into the coda of a syllable before the /w/ does not render these sequences well-formed. The sequences are not allowed no matter how they may be syllabified.

Purely sequential regularities obviously exist. If all phonotactic regularities were sequential, they could be handled by a finite state grammar, which is the simplest available formalization and which provides no constituent structure. Therefore, to argue for a constituent structure, it is necessary to demonstrate the existence of regularities which go beyond those captured without any constituent structure.

Going beyond finite-state grammars, the next more complex type of grammar defined in the Chomsky hierarchy is the context-free grammar. Context-free grammars provide a way to describe certain non-sequential dependencies which cannot be characterized by finite-state grammars. The set of well-formed strings in a context-free language is enumerated by a set of phrase structure rules which have a single symbol on the left and a symbol or sequence of symbols on the right. The derivation may be graphically represented in a tree, with any label appearing on the left-hand side of a rule corresponding to a non-terminal node in the tree.

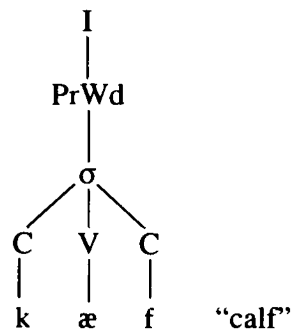
Probably the most widely accepted type of constituent in phonology is the syllable itself. Although the generalizations supporting the syllable can be "compiled out" into a finite-state grammar, most researchers find a context-free formalization more insightful. To exemplify context-free grammars, consider a "mini-English" in which intonation phrases (I) consist of one or two prosodic words (PrWd), words consist of one or two syllables (σ), and syllables have the form CV or CVC. Rules expressing these generalizations are:

(3)

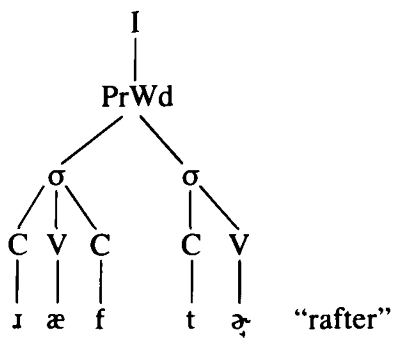
I	→	PrWd
I	→	PrWd PrWd
PrWd	→	σ
PrWd	→	σ σ
σ	→	C V
σ	→	CVC

Suitably augmented with rules rewriting the symbols "C" and "V" with actual phonemes of English, productions of (4) and (5) include:

(4)



(5)



In these tree structures, the constituents appear as intermediate level nodes. Mini-English does not include the words "raft" or "after" because it makes no provision for words ending in two consonants or beginning in a vowel. Mini-English also contrasts with regular English in having no stress. To describe stress patterns, a more complex grammar with metrical foot (F) nodes is needed (see Selkirk, 1980; Hayes, 1995). The syllable, the metrical foot, the prosodic word and the intonation phrase thus represent four reasonably uncontroversial types of prosodic nodes. Though some researchers posit additional node types (e.g. the "mora" of Hyman, 1985; Hayes, 1989; and McCarthy & Prince, 1986; the "cola" of Halle & Vergnaud, 1987, and the "Phonological Phrase" in Selkirk, 1984), the total number of different node types in even the most elaborated theories is still small.

In context-free grammars in general, the same symbol can appear both on the left of a rule and on the right of that same rule or some other rule. This power is used to describe recursive constructions, for example, syntactic constructions with clauses inside clauses.

(6) [Jack told us [that Mary is planning [for the 3rd graders to take a field trip [to see the Chicago Historical Society]]]]

This freedom of embedding is not found in the phonological grammar. PrWd is the only node type which is a serious candidate for being recursive (see Ladd, 1986; Prince & Smolensky, (in press). Otherwise, all nodes at the same height in the prosodic representation are of the same type and each type of node can dominate nodes only of a specific next lower type. For example, a metrical foot can dominate only syllables, not words, intonation phrases, or other feet. This observation is made rigorous in Selkirk's "Strict Layer Hypothesis" (Selkirk, 1984; see also Nespor & Vogel, 1986; Beckman, 1986; Pierrehumbert & Beckman, 1988).

Putative examples of recursion on PrWd (various types of compounds) will not concern us here. However, another way in which PrWd violates Strict Layering will be of central importance. In many languages, including English, PrWd may exhibit extra ("stray" or "extraprosodic") material at the edges. Specifically, as originally shown in Hayes (1986), the word may have an extra syllable at the end (beyond what can be parsed into canonical metrical feet); furthermore, the last syllable may have one or more extra consonants beyond what would normally be parsable into the coda position. Stray consonants at the beginning of the word are also a linguistic commonplace, with the strongest candidate for such a status in English being word-initial /s/ before plosives (see Treiman, Gross, & Cwikiel-Glavin, 1992).

The presence of extra consonants at the word edge may be appreciated by examining words such as "strange" /streyndʒ/ or "camped" /kæmpt/. Words of this type lead to the supposition that a syllable can begin with as many as three consonants, and likewise end with three consonants. If this were really so, then the phonotactic rule which expands the metrical foot into syllables should make it possible to concatenate a syllable beginning in three consonants to one ending in three consonants. In short, it should be possible to find disyllabic words with as many as six consonants in a row, such as "amptstra". Such words are actually impossible. An exhaustive study of the Collins dictionary reveals that the maximum is four (as in "constrain") and even combinations of three or four consonants are highly restricted (see Pierrehumbert, 1994b).

Studies supporting this same claim with various types of evidence, in various languages, include Fujimura and Lovins (1977), Hayes (1986), McCarthy (1985), Goldsmith (1990), Kaye, Lowenstamm, and Vergnaud, (1990) and F. Dell (1995). The Fujimura and Lovins study is notable for demonstrating that the stray coronal consonant in morphologically complex words such as "camped" and "flames" is phonetically less well integrated into the syllable than other post-vocalic consonants; the term which they introduce for consonants in this class is the "affix" The net consequence of these results is that great caution must be exercised in interpreting allowable patterns at word edges as indicative of the shape of syllables in general.

Phonotactics and internal constituency of the syllable

The foundation just presented makes it possible to evaluate claims that the phonotactic regularities of English reveal the existence of the onset and the rhyme as internal constituents of the syllable. The general form of such arguments is that the onset and the rhyme provide domains for particularly close statistical dependencies. A recent and fairly comprehensive study which attempts to make such an argument is Fudge (1987). Hence, we examine Fudge's argument in some detail.

As already noted, constituent structure should only be posited when a purely sequential analysis is shown to be inadequate, because mathematical models with constituents are more complex than ones without. Failure to appreciate this point undermines the value of Fudge's study. For example, the impossibility of word beginnings in /sb/, /sd/, /sg/ and in /bw/, /pw/ is presented as evidence for the syllable onset as a constituent. As already discussed, these combinations are impossible even across a word-internal syllable boundary and hence represent examples of purely sequential lexical constraints.

A further weakness of Fudge's study is that is does not separate properties of the syllable per se from properties of the foot or the word. For example, in discussing the evidence for the rhyme as a constituent, Fudge says:

(7) "Against this must be set the very general constraints which clearly hold between Peak and Coda in English:

a) Word-final stressed syllables must be closed if they contain a short vowel (...)"

(Fudge, 1987; p.369)

The constraint just alluded to is not a constraint operating between the Peak and the Coda within the syllable, but rather a constraint on the foot, which for English must have at least two morae (see McCarthy & Prince, 1990b). That is, a minimal foot may have a single dimoraic syllable (as in "can" or "grey") or two monomoraic syllables (as in "papa" "apple" or "feta"). The disyllabic foot can only have the stress on the first syllable; the second syllable is unstressed. This generalization pertains to word-final feet just as to other feet. Since the foot structure constraint can be met either by a single heavy syllable or by two light syllables, it cannot be a syllable-internal constraint and therefore does not bear on the question of syllable-internal constituency.

Fudge's study also shares a short-coming which is very widespread in the field, that of neglecting to evaluate non-occurrence of particular combinations of elements against the rate of occurrence to be expected if the elements were independent and combined at random. Suppose that the Northern Lights are observed in St. Louis, Mo one day in 7300, on the average; similarly, suppose that the waters of the Mississippi rise above the levee one day in 36,500. The expected value for observing the Northern Lights on a day on which the Mississippi has risen above the levee is then 1 in 266,450,000 days. If a person never observes this combination, he or she is still not justified in positing any interdependence between the Northern Lights and the level of the Mississippi. Independent probabilities alone suffice to explain the absence of the combination in any practically available data set. Similarly, the absence of particular combinations of phonemes from the lexicon of a language is only noteworthy if the expected count in a word set of the size of that lexicon is significantly greater than zero.

Fudge's Tables I and II of Onset-Peak and Peak-Coda combinations cannot be evaluated because the observed counts are not compared to the counts to be expected through random combination of the components (which are the consonant clusters on the vertical axis of the tables and the vowels on the horizontal axis). Just a few informal observations about rare phonemes are made in the text. As a case in point, consider the issue of how /sp/ combines with various vowels. In the on-line Collins, /sp/ is found word-initially in 581 different words, but word-finally in only 17 words. It follows that for any vowel V, the combination /sp V/ is more than 30 times as likely as the combination /V sp/. The difference in positional probabilities is probably sufficient to explain the fact that so many of the cells of Table I representing /V sp/ combinations show 0 counts; no co-occurrence relations between the V and /sp/ need be proposed. Moraic theory could handle this situation by associating different probabilities with moraic as opposed to nonmoraic /sp/ combinations. As mentioned above, the word-beginning /sp/ is probably parsed as /s/ attached to the word and /p/ attached to the syllable.

It should also be noted that Fudge's study evidently concerned monosyllabic words only, and that the total number of monosyllabic words in English is only a few thousand. Hence most expected counts for these tables would be very low. This makes it difficult to determine whether the underrepresentation of any particular combination in the tables is statistically significant. To effectively address the issue of expected against observed rates of occurrence, it is necessary to obtain a much larger set of syllables, for example by carrying out a syllabic parse of all words (whether monosyllabic or not) in a dictionary. Randolph (1989) describes an extremely careful information-theoretic study of a fully parsed 20,000 word dictionary (the Merriam-Webster Pocket Dictionary). Even for this larger data sample, none of the mutual information values between different positions in the syllable proved to be statistically significant. His conclusion is that "on the basis of these data, the null hypothesis (no privileged groupings) is not to be rejected" (p. 145–146).

In information theory, amount of information (in bits) is a function of the number of the categories which contrast and of the relative probabilities of these categories. For example, a system with a distinction amongst three equiprobable categories carries more information than a system distinguishing amongst just two equiprobable categories. If the three categories have imbalanced probabilities — such as .45, .45 and .10 respectively — then they carry less information than if the probabilities were equal because the system is in effect on its way to being a system with only a binary contrast.

In many languages, the space of consonantal contrasts is less informative, in the technical sense, for post-vocalic consonants within the syllable than for pre-vocalic consonants. In some languages, this reduction is very drastic. For example, in Japanese the only contrast which survives in this position is the distinction between nasals and non-nasals (see Ito, 1988); the place of articulation is fully predictable. English appears to have a tendency in the same direction, though a less extreme one. For example, at the beginning of the word the clusters /sp/, /st/, and /sk/ have relative frequencies of .36, .54, and .09 respectively (in the Collins dictionary). At the end of the word, in contrast, the relative frequencies are much more imbalanced, at .02, .91, and .06, respectively. Although /sp/ and /sk/ do occur at the end of the word, the system of contrast amongst the three clusters is less informative in this position because the probabilities are much closer to those of a system permitting only a single outcome (/st/), with 0 probabilities for /sp/ and /sk/.

A consequence of fully or partially collapsing consonantal contrasts in post-vocalic position is that VCs carry more information than CVs. This consequence follows from the amount of information carried by the C alone, without bringing in additional assumptions about the relationship of the C to the V. This point is appreciated in Dell, Cornell, and Govindjee (1993), which exploits positional probabilities in a connectionist model of speech errors in CVC words. With unusual carefulness, they show that the relative uninformativeness of VC combinations does not constitute an argument for the rhyme as a constituent in the cognitive representation of sound structure. Without directly representing onset or rhyme constituents, their model obtains the pattern of errors previously held to motivate such constituents. Difficulties they encounter in modelling the speech errors for polysyllabic words appear to arise from the fact that the model lacks the larger scale prosodic features needed to align polysyllabic words with each other (see discussion below).

A further topic of debate in statistical studies of phonotactics has been whether co-occurrence restrictions amongst consonants within the onset or within the rhyme are more frequent or statistically stronger than those between the onset and the coda. Insofar as onset-coda distinctions are just as typical as within-onset or within-coda distinctions, they weaken the case for any privileged groupings within the syllable. Clements and Keyser (1983) make note of systematic gaps in combinations of onset and coda, such as the absence of words like */flɪl/. Their observations are strengthened by Davis' studies of the Merriam-Webster pocket dictionary (Davis, 1992; Davis, 1989b). In general, improved technology for statistical studies of large on-line data sets has made it easier to discover nonlocal dependencies which had previously escaped scholarly notice. Nonetheless, onset-coda restrictions will probably prove to be relatively uncommon or weak. A simple reason for this fact is that phonological dependencies typically weaken with distance. Greenberg (1950) and Pierrehumbert (1993) present statistics documenting this fact for the co-occurrence restrictions for consonants within the verbal roots of Arabic, which are statistically weaker (though still in evidence) for the first and third consonants than for the first and second or second and third; as already discussed, these constraints cannot be treated as constraints relating to syllable structure. Berkley (1994a,b) presents related statistics demonstrating the weakening of OCP-Place in English with the number of intervening phonemes.

So far, we have demonstrated that phonotactic evidence which has been advanced in support of the onset-rhyme model is not as strong as it first appears. By Occam's razor the formally simpler flatter models are then to be preferred. However, the case for flatter models can also be stated more positively, because the onset-rhyme model actually creates impediments to the expression of major phonological regularities.

As discussed in Hayes (1989), many languages exhibit morphophonemic alternations in which loss of a coda consonant entails lengthening of the preceding (tautosyllabic) vowel. Such phenomena can be described in moraic theory (as well as in some related models) by allowing the last structural position of the syllable to be occupied either by the features for a consonant or by the features shared with the preceding vowel. This solution is not available in theories such as Fudge's (diagrammed in (1) above), in which different syllabic positions are highly specified for the type of segment they will accept.

Many languages have quantity sensitive stress rules, which refer to syllable weight to determine the location of primary and/or secondary stresses in words. Typically, either a long vowel or a combination of a vowel and a post-vocalic consonant renders a syllable heavy. This equivalence is transparently represented in moraic theory; heaviness can be determined from the number of morae that the syllable immediately dominates, which is one for light syllables and two for heavy syllables. Furthermore, the frequently observed equivalence of heavy syllables to pairs of light syllables in stress systems is readily handled by saying that the metrical feet are bimoraic, irrespective of syllabification. Readers are referred to Hayes (1995) for an extensive typology of stress systems and a detailed theoretical treatment using a moraic approach. In onset/rhyme theory, it is much more problematic to describe the observed equivalencies amongst long vowels, syllables closed by a consonant, and pairs of light syllables. The topmost hierarchical division in the syllable (that between onset and rhyme) has no bearing on weight. Within the rhyme, long vowels and vowel-consonant combinations have different structural representations. There is no formal support for describing the equivalence of heavy syllables to pairs of light syllables.

In summary, much work on the syllable has exaggerated the evidence for syllable internal constituents by 1) positing hierarchical structure in cases in which purely sequential constraints offer equal or better coverage 2) attributing to the syllable all regularities found within monosyllabic words without considering the roles played by other prosodic nodes 3) failing to examine whether nonexistent sequences are significantly underrepresented from a statistical point of view. In work which corrects some or all of these past failings (such as Davis, 1992, 1989b; Lamontagne, 1993; Randolph, 1989) the linguistic evidence for internal constituency in the syllable is found to be considerably weakened. In addition, some recent work in the moraic framework actively militates against the onset-rhyme model by displaying the importance of equivalencies which this more highly articulated model cannot readily capture.

TASKS AND THEIR THEORETICAL INTERPRETATION

Language game experiments seek to discover the prosodic constituency of words by causing subjects to transform the words in some way.

(operation)

(8) Input word or words --------------------------------------→Output

The operation represents the subject's internalization of the instructions for the experiment, and the experimenter has no direct access to this internalization. Rather, he or she attempts to infer it from the observable data, namely input/output correspondences.

The interpretation of these correspondences should be understood in the light of the linguistic results on the naturally occurring operations most similar to those invented by the experimentalists. That is, in our view, language game experiments are efforts to teach subjects a new process of word formation. We believe the games will be internalized, insofar as is possible, in a fashion which reflects both previously existing processes of word formation in the language, and the possibilities of language in general. Since language game experiments are very short compared to the natural process of language acquisition, it is, however, to be expected that the outputs may be more variable than those of a stable adult grammar.

A major issue in theoretical studies of word formation has been the extent to which complex forms (the "output" in (8)) are determined by an analysis, whether segmental or structural, of the input. In transformational models, complex forms are derived by rules which analyze simpler forms and change them if their structural descriptions are met. Under a transformational approach, it is not unreasonable to assume that complex forms reveal the analysis of related simpler forms in a rather direct fashion. The specific fashion in which transformational rules reveal the analysis of base forms is not, however, what is sometimes assumed in the psycholinguistic literature. A typical structure-sensitive rule identifies an instance of one node type and does something to it; for example, a movement rule in syntax might find a wh-word and move it to the front of the sentence, or find a complex NP and move it to the end. For a mathematical treatment of the concepts of "constituent" and "residue" (or everything that remains after a constituent has been identified) see also Bach (1979, 1984) and Hoeksema and Janda (1988). Taking the transformational approach into the arena under discussion, a grammarian might suggest that subjects carry out language games by identifying an onset constituent and manipulating it, or by identifying a rhyme constituent and manipulating it. But contra Treiman (1986), the preferred division point shown in a single language game does not provide evidence for both of these constituents simultaneously.

Transformational models of phonology have been attacked since their very beginnings on the grounds that they give short shrift to the pervasive role played by output prosodic structure in determining the final shape of words, including both simple words and complex words. In current theoretical understanding, the role of transformational rules has been considerably reduced and in many frameworks it has been eliminated altogether. The one uncontroversial essential is that the final shape of every form be properly parsable into syllables, feet, and prosodic words. Various languages have various processes and strategies for coercing words into good prosodic form; the characterization of these processes and strategies is a matter of controversy. Under almost any current account, prosodic structure of the input in (8) above cannot play a role unless it survives coercion of the output into good prosodic form. Therefore, we assume that producing a prosodically well-formed output is a high priority for the subjects in any language game experiment.

Word-word alignment processes

In order to clarify further the parallels between natural language and psycholinguistic experiments involving language games, it is useful to draw a distinction between natural processes which involve the interaction of two or more different words, and ones which might be thought of in terms of deriving a complex form from a base form. We will show that natural processes involving the interaction of two or more words do not generically manipulate prosodic constituents. As a result, related experimental tasks are not good prospects for providing information about constituency of input words. Derivation of morphological complex forms from simple ones provides a more promising source for experimental data on this issue, because at least some results from natural language suggest that the prosodic parse of the simpler form may have consequences for the more complex forms.

Four phenomena that involve word-word alignment are rhyming, blending, lexical priming, and speech errors. When examined in their full generality, these tasks prove not to manipulate prosodic constituents. The conclusion will be that interactions amongst words are to be understood not in terms of constituency, but rather in terms of alignment of the words to each other at psychologically salient points, especially at the edges and at the prominently stressed syllables.

In rhyming, neither rhyming word can be derived from the other. The two words (or phrases) are on a par; if they correspond in a certain way, they constitute an example of a rhyme, and otherwise not. Here are a number of rhymes drawn from Byron's Don Juan, as discussed in Pierrehumbert (1994a). A " I " indicates the division point between the nonmatching and matching parts of the rhymed material.

(9)	c I ell	dw I ell		(Canto XIV, 81)
	wh I y	s I igh		(Canto XIV, 81)
	v I ogue	r I ogue		(Canto XIV, 38)
(10)	l I eaves	rec I eives	gr I ieves	(Canto XIV, 78)
(11) a.	perpl I exes	s I exes		(Canto XIV, 73)
b.	I Adeline	so b I ad a line		(Canto XIV, 46)
c.	flirt I ation	corpor I ation		(Canto XIV, 43)
d.	frag I ility	sensib I ility		(Canto XIV, 46)

Examples of rhymed monosyllables such as (9) might give the impression that rhyming is readily described in terms of onset and rhyme constituents of the syllable; the onsets must be different and the rhymes must be the same. This impression is already called into question by examples such as (10). The mismatched regions have disparate prosodic status; /l/ is a subpart of a syllable whereas /ɹɪs/ is more than a whole syllable. The matched part includes not only the rhyme of the syllable, but also the clearest case in English of an "extra" consonant directly depending on the prosodic word node, namely the affix suggested in Fujimura and Lovins (1977).

As previously noted in Davis (1989a), feminine rhymes (illustrated in (11)) provide even stronger evidence that poetic rhyming does not manipulate a rhyme constituent. In (11a), the left hand member of one of the rhyming words is a subpart of a syllable, whereas for the other, it is more than a syllable. In (11b), a word is matched to something that is bigger than a word. In short, the domains set up by the rhyming cross-cut the syllable structure, and even the word structure, despite the fact that the syllable and the word are clearly the most significant domains for phonotactic constraints. One might view feminine rhymes as a kind of loose analogic extension of masculine rhymes. Evidence against this view is reported in Pierrehumbert's (1994a) study of Byron's rhymes (Byron, 1949); statistics on the rates of phonemic matches before the head vowel and mismatches at or past the head vowel show that feminine and masculine rhymes are remarkably similar in their statistical variation and should probably be viewed as manifestations of a single cognitive process.

Shattuck-Hufnagel (1985) used a speech error induction paradigm to explore how stress and word boundaries interact to determine the frequency of speech errors involving the interaction of two segments (as opposed to errors involving substitutions without contextual motivation). The study builds on a large body of work, beginning with Fromkin (1973), showing that interaction errors preponderantly involve segments in analogous prosodic positions. Shattuck-Hufnagel looked at the errors in tongue-twisters such as

(12) parade fad foot patrol

Statistical analysis of the errors showed that consonants beginning a stressed syllable are more subject to error than those beginning an unstressed syllable. Consonants beginning a word are more subject to error than word-medial consonants. Furthermore, there is a cumulative interaction between the stress and the word boundary, such that consonants beginning a word with initial stress are most error-prone of all. As noted in Davis (1989a), the partition implied by an error in the initial consonant of a polysyllabic word crosscuts what would otherwise be considered to be the constituent structure. Shattuck-Hufnagel (1987, 1992) also discusses the special status of the consonant or group of consonants beginning a word.

A study of lexical priming in reading by Forster and Taft. (1994) explores how regions of orthographic identity in monosyllables contribute to lexical priming. Statistically significant evidence for both a "body" (consisting of the vowel up through the end of the word) and an "anti-body" (consisting of the word onset through the vowel) are found. Discontinuous regions of match exhibited a significant effect when two circumstances combined; the matches were found at the word edges (as in "plain"- "ploin" but not "lin"- "flint"), and the words had relatively few orthographic neighbors. Since the "body" and the "anti-body" both include the vowel, they cannot be integrated into a single tree structure and thus are not examples of constituents in the sense of formal language theory; discontinuous matches are still less examples of constituents. However, the psychologically relevant regions can be defined by combined reference to edges and heads.

A study of blending of monosyllables carried out by Treiman (1986) establishes that the preferred blending strategy for monosyllables with an affix is to take from the first component word the segments up to the stressed vowel, and from the second component the segments from the stressed vowel through to the end. Examples from her study include:

(13) packed + nuts → putts
billed + guns → buns

Although Treiman interprets these results as providing evidence for the rhyme, this interpretation is at odds with the phonotactic evidence, which indicates that the suffixes on these forms are direct dependents of the word node. The subjects' strategy is readily described as a head based strategy which cuts over from one word to the other at the head vowel.

Blending is a semi-productive source of neologisms in American English, so that the task in Treiman's experiment was not totally novel to the subjects. The preferred blending strategy appears to be based on extensive childhood experience with rhymes. It is most productive when the beginning of the first vowel and the beginning of the stressed vowel coincide (e.g. br | eakfast + l | unch → brunch), thus presenting a parallel to the results on speech errors. However, other factors also play a role, as shown by the following excerpt from a 3rd grader's story: "Vivian the flamingo got married to an ostrich and then they had some sweet little ostringoes." Note that | ostrich + flam | ingo → ingo would create a blend which had no phonological trace of one of the lexical components. Considerations of informativeness have led the author to misalign the stresses of the components in constructing the blend.

Independent support for the claim that the edges and heads are privileged positions in prosodic representations comes from many related aspects of sound structure. Work on lexical stress from Liberman and Prince (1977). Prince (1983), through McCarthy and Prince (1994) shows that languages with predictable word stress assign this stress with reference to one of the word edges (either the initial edge or the final one). Prince and Smolensky (in press) and McCarthy and Prince (1994) also discuss the resources languages bring to bear in maintaining the alignment between the morphological and the prosodic edges of forms. For example, syllabification frequently fails to cross word boundaries. They also show that the edge provides a reference point for affixation even when the final result is infixation; in languages they discuss, affixes whose basic locus of attachment is the beginning or the end of the word move minimally in from the edge in accordance with output constraints. In the intonational system, the phrase boundary provides a locus for extra tones which mark the boundary phonetically and which convey information about the discourse status of the phrase (Pierrehumbert, 1980; Pierrehumbert & Beckman, 1988). Allophonic effects of word and phrase boundaries include alteration of the voice source characteristics and lengthening of the immediately preceding syllable; phonetic studies of interest include Nakatani, O'Connor, and Aston (1981), Beckman and Edwards (1990), Beckman, Edwards, and Fletcher (1992), and Pierrehumbert and Talkin (1992).

The importance of the prosodic head is illustrated by its role in determining pitch accent placement in languages such as English which have dynamic stress (see Liberman, 1979; Pierrehumbert, 1980; Pierrehumbert, 1994a). This may be viewed as an example of entrainment, discussed in Gallistel (1980) under the name of "the magnet effect" An example of entrainment would be the tendency of a drummer to step in synchrony with his drumbeats. Work since Jackendoff (1972) shows that the prosodic head of a phrase has a salience which attracts the scope of quantifiers, negatives, and other adverbials; consider the difference in meaning between "I only want ONE cookie" and "I only want one COOKIE" Prosodic heads also receive distinct allophony, being articulated in a way which is both more complete (see deJong, 1994) and which more fully manifests the syllable profile (Pierrehumbert, 1995). In addition, the intonation system exhibits a tendency to bring edges and heads together by inserting phrasing breaks just before or just after focused elements; see Pierrehumbert and Beckman (1988).

In conclusion, processes involving word-word alignment are nonderivational. The prosody of the two words plays a role analogous to entrainment in motor control theory; preferred alignment points are the edges of the word and at prosodically prominent locations. These alignment points can establish partitions or correspondences which cross-cut the constituent structure suggested by the phonotactics. In addition, multiple alignment factors may exhibit a cumulative force. In view of these results, experimental paradigms which tap word-word alignment provide at best problematic evidence about phonological constituency.

Word transformation processes

In many experimental paradigms, in contrast to the paradigms just discussed, subjects are given only a single word as input. They modify it in some fashion to produce an output. If the output is a single word, then there are significant parallels to those natural processes of word-formation which are responsible for the phonological shape of morphologically complex words.

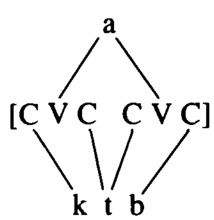
English is mainly prefixing and suffixing. It makes only marginal use of morphological processes which manipulate internal subparts of words. Familiar examples are the strong verbs (e.g. "ring", "rang") and a set of semi-reduplicative colloquialisms (e.g. "willy-nilly", "higglety-pigglety" "flim-flam"). However, other languages make extremely heavy use of infixation, reduplication, and various internal modifications of word stems. Such processes are the subject of the extensive literature on prosodic morphology, a few of whose highlights include: McCarthy (1985), Marantz (1982), Steriade (1988), Archangeli (1991), McCarthy and Prince (1990a, 1990b, 1994); Lombardi and McCarthy (1991), Ito and Mester (1992). This is the literature which provides natural language analogues to experiments in which subjects insert infixes into words or modify internal subparts of words.

One of the key insights of the prosodic morphology literature is the concept of template-mapping. The analysis of Arabic in McCarthy (1985) explicates the verbal paradigms of Arabic by positing CV templates (structural templates for the output which consist of consonantal and vocalic slots). Onto these templates are mapped the consonantal melody (provided by the verb stem) and the vocalic melody (provided by a derivational or inflectional morpheme). For example, "kattab" is represented as in (14); the consonant sequence is provided by the verbal stem (meaning "write"), and the structural template and the vowel are contributed by the causal morpheme.

(14) Vowel melody tier

CV-template tier

Consonantal root tier



When this analysis appeared, it was immediately understood to be far more elegant than the host of transformational rules which are required to describe a nonconcatenative morphological system in a derivational framework. Subsequent work has retained the concept of template-mapping while seeking to systematize and explain the types of templates available and to understand the interaction of morphologically supplied templates with those generically provided by a language's prosodic system.

As further examples of template mapping in natural language, consider the verbal systems of Alabama and Yawelmani. As shown in Montler and Hardy (1991), the standard (or nonperiphrastic) negative affix of Alabama has five different surface shapes: a prefix /ik-/ infixes /-ki-/, /-kii-/, /-ik-/ and a suffix /-ki/. Previous work described the form of the affix as an idiosyncratic result of membership in a verbal paradigm. However, Montler and Hardy show that the form of the affix is predictable from the phonological form of the stem, as summarized in (15)–(20). /ik-/ is prefixed to the rare stems consisting only of a light syllable:

(15)	CV	→	*ik*CV	
	(i)la		*ik*lo	"come"

Infixation occurs for stems ending in any of the following patterns:

(16) ... VCCV] → ... V*ki*CCV
talwa ta*ki*lwo "sing"

(17) ... VVCV → ...V*kii*CV
hoopa ho*kii*po "sick"

(18) ... XkV → ....X*ik*kV
liska lis*ik*ko "beat"

/-ki/ is suffixed to stems which end in VC or which end in two light syllables but can lose their last vowel by syncopy:

(19) ... VC → ... VC*ki*
bit- bit*ki*- (→ bitko by further suffixation) "hit"

(20) ...VCV → ... VC*ki*
isi- is*ki*- (→ isko) "take"

The common denominator which largely explains these various outcomes is the requirement that the result (the negated verb) meet the prosodic template for the verbs of Alabama. Verbs (unlike nouns) must end in a heavy syllable followed by a light syllable. The affix is placed near the end of the word in a way which accommodates this end. Note that it is not possible to describe the affix as positioned in any fixed way relative to the prosodic structure of the input (the stem). For example, in (15) the affix is a syllable on its own which is placed before another syllable. In (16), in contrast, the affix is inserted into the middle of a syllable between the nucleus and the coda.

In Alabama, the template onto which the output is mapped is quite general for the language, since it pertains to all verbs, if not to all words. In Yawelmani, as discussed in Archangeli (1991), particular verbal suffixes provide particular templatic forms onto which the stem is mapped. The verbal alternations of Yawelmani, widely discussed since Newman (1944) and Kuroda (1967), are exemplified by various forms of the stem /hiwt/ shown in (21) (reproduced from Archangeli).

(21)	abstract form	after vowel allophony	gloss
a)	hiwiit-iin	hiweeten	'will walk'
b)	hiiwt-(?)ihni	hew'tihni	'one who is roaming'
c)	hiwt-(?)in'ay	hiw'tin'ay	'while walking'

As Archangeli shows, each of the verbal suffixes in (21a-c) imposes on the stem (or on the beginning of the word) one of three prosodic templates: an iambic foot (or a light syllable followed by a heavy syllable), a heavy syllable, or any syllable, respectively. All other details of the output forms follow from the interaction of these morpheme specific templates with general properties of Yawelmani syllabification, which aggressively accommodates otherwise unsyllabifiable material via epenthesis and vowel spreading. She shows that her analysis is superior to prior derivationally oriented analyses because it demonstrates an underlying unity between the verbal paradigms and the system of reduplication found in nouns.

In both of the analyses just reviewed, the prosodic parse of the output is decisive and the prosodic structure of the stem does not play a role. Can the prosodic structure of the base form be relevant to morphophonemic processes? Although this question is controversial, there is some evidence that it can be. One of the clearer examples is found in Steriade's study of reduplication (Steriade, 1988). This study focuses on Sanskrit, though Steriade shows that the patterns of Sanskrit find parallels in processes of productive reduplication in other languages as well.

Reduplication in Sanskrit is prefixing. It is quite complex because it interacts with the system of vowel insertion and syncope which gives rise to the "full grade" and the "zero grade". Furthermore, the template onto which the reduplicated material is mapped has relatively few structural positions, and for many stems this results in consonants being dropped out in the reduplication.

(22a) and (22b) illustrates reduplication without loss of material. In (22c), the second consonant of the onset and the second consonant of the coda are lost because they exceed the template.

(22)	Root	Intensive form (full grade)	Intensive form (weak grade)	Gloss
	a. pan/pn		pan-i-pn-at	"admire"
	b. gam/gm	gam-gam-		"go"
	c. krand/krnd	kan-i-krand-	kan-i-krnd-	"cry out"

In Steriade's discussion, the critical examples are those in which reduplication interacts via grade alternation with a vowel-glide alternation, for example:

(23)	svap/sup	sa:-svap-	sau-sup

In the weak grade, the high back labial vowel /u/ takes up the nuclear position of the stem because the /a/ is absent. In the weak grade reduplicated prefix, it shows up in the coda. In the strong grade, the presence of /a/ in the stem places /u/ in the onset (where an allophonic process changes it to [v]); in the reduplicated prefix, it is lost just as the /r/ in /krand/ is. Steriade argues that the reduplication cannot just blindly map the phoneme string of the base onto the prefix template; it protects information about whether phonemes are onset or non-onset phonemes in the stem by mapping onset material to onset position and rhyme material to rhyme position. Note that the mapping does not preserve the full level of positional detail available in the onset-rhyme tree presented in (1) in the introduction. To derive the form /sau-sup/ (rather than /su:-sup/), it is necessary to place the /u/ in nuclear position in the stem but in coda position in the prefix. For this particular set of alternations, it is sufficient to protect the moraic or nonmoraic status of the phonemes copied.

Steriade also shows that stems beginning in s-obstruent provide a contrast to stems like /krand/ above. In the reduplicated forms, the obstruent is preserved despite the fact that it is second in the cluster; to simplify the cluster, the /s/ is lost instead. The difference is due to the fact that the /s/ (unlike the /k/ in /krand/) is extrasyllabic, depending directly on the prosodic word. A technical analysis depends on allowing the reduplication to refer to whether a consonant is parsed into a syllable at all in the base form. This situation provides another example in which a morphophonological process must refer to the prosodic parse of the base form. However, it also reinforces the point made above that the consonant sequences beginning words often do not behave like constituents because words can have extra material at the edges.

The interaction of morphology with stress assignment provides a further class of cases in which prosodic structure of the base form is carried over into a derived form. A classic example in English is behavior of the deverbal affix "al" which attaches only to verbs with final stress. For example, English has "refer" "referral" "acquit" "acquittal" "intersperse" "interspersal" But it is not possible to form "exittal" from "exit" or "circumvental" from "circumvent" This affix is not to be confused with the denominal "al" found in "bride", "bridal", which is not stress-sensitive. For deverbal "al" the stress pattern of the stem is critical in permitting or blocking the affixation. Furthermore, the location of the stem stress is maintained in the derived form; in the experiments described below, transfer of the base form stress to the derived forms will turn out to be a critical factor in explaining the results. Kaisse and Shaw (1985) discuss the significance of affixes such as deverbal "al" for the theory of Lexical Phonology. Inkelas (1989) adapts the concept of subcategorization (familiar from the theory of sentence grammar) to provide a theoretical treatment of many similar examples in various languages.

In conclusion, language games involving transforming a base form into a single output word have more promise for revealing information about the prosodic structure of the base form than games involving word-word interactions. This promise is present because there is at least some evidence that morphophonemic processes can refer to the prosodic structure of base forms. However, even for such processes, mapping onto output templates still has a major role. The output templates may be associated with particular morphemes rather arising from the prosodic system of the language in general. Furthermore, in cases in which the internal syllabic form of the base form is relevant, it so far appears that the full detail of syllabic templates like (1) may not be invoked. Hence, the question requires further exploration, and the experiments described below were exactly designed to contribute to this exploration.

Treiman's proposals

The series of experiments to be discussed applied the infixation paradigm used in some of the experiments of Treiman (1983). The paradigm is a concept generalization paradigm using novel word games. First, subjects are presented with models of infixation into a monosyllabic base form beginning with a single consonant. After a training phase in which they acquire and demonstrate mastery of this basic pattern, they begin a test phase in which they must respond without further instruction or feedback. The test phase includes more complex base forms for which two or more different output forms are possible in principle. Subjects' choice amongst the different candidate outputs reveals the form of the rule or strategy that they acquired from the models and training.

Our experimental design differed from those in Treiman (1983), Fowler et al. (1993), and Treiman et al. (1995) in requiring the subjects to produce a single noncompound word as an output. Materials were carefully designed so that none of the possible outputs included any phonemic sequence which would be impossible in a monomorphemic word. In contrast, Treiman (1983) includes candidate outputs with medial clusters which could only be found in compounds, for example:

(24) skɛf → skæz ɛf or *sæz kɛf
twʌl → twæz ʌl or *tæz wʌl

In her review of the present article, Treiman informs us that subjects in the (1983) experiment produced a sequence of two words as the output for each stimulus. Although Fowler et al. (1993) and Treiman et al. (1995) claim to describe language game experiments on polysyllabic words, the examples presented include many violations of word-internal phonotactics, both in the inputs and the outputs. Deviant clusters include: obstruent clusters containing a voiced element (c.f. discussion of Lamontagne, 1993, above); /h/ after an obstruent; and velar-labial sequences (c.f. Yip, 1988; Pierrehumbert, 1994b). Indeed every example given in the text of Treiman et al. (1995) includes a cluster which is not attested word-internally in English, as shown by a computerized search of the 70,000 word on-line Collins. The problematic clusters are found in the dictionary only across a word boundary.

There are three reasons for our insistence on phonotactically normal words as inputs and outputs. First, if subjects in any way prefer to produce a single word output, then this preference will dispose them in favor of the first outcome in cases like (24) rather than the second. That is, any preference for producing a single word output would provide a reason for preserving the onset in the output, independent of the cognitive representation of the input. One of the aims of our own experiments was to determine whether this possible artifact played a role in Treiman's original findings. Second, as discussed above, the derivation of morphologically complex words is the area of natural language in which the prosodic constituency of base forms may play a role in the output. Natural processes of word-word alignment seem to refer to edges and heads without manipulating constituency. Processes with single word outputs are those for which the use of underlying constituency is an open issue.

Third, we believe that the rather problematic results of Fowler et al. (1993) reflect the fact that some subjects analyzed the stimuli and outputs as compounds or phrases rather than as single words. Specifically, Fowler et al. (1993) report that students from Wayne State University who were tested on trisyllabic words of the form CV.CVC.CVC showed an effect of syllable constituency for the syllable. Students from Dartmouth College tested on similarly constructed disyllabic words did not.

Treiman et al. (1995) suggest that this unexpected difference in outcomes may be due to a difference in the subject pools at the two universities. Dartmouth College is an elite institution with much more selective admissions that Wayne State University, and its students on the average have higher scores on tests of verbal ability. Treiman et al. propose that the lower verbal Wayne State students used syllable structure, whereas the higher verbal Dartmouth students found the task so easy that they used phoneme sequencing only. The grounds for proposing this particular connection between verbal ability and strategy is unclear to us. We would suggest instead that the lower verbal Wayne State students analyzed the nonsense words in the experiments as compounds or phrases because of the many clusters which cannot be found word-internally. Pierrehumbert's (1994b) experimental study on triconsonantal medial clusters demonstrates exactly that phonotactic violations cause nonsense words to be analyzed as compounds. Hence, these students probably adopted a strategy based on extracting and then manipulating a word in the compound. The higher verbal Dartmouth students, whose vocabularies would include many phonotactically irregular foreign borrowings, may have been more willing to accept the nonsense stimuli as single words. If so, they would be less able to extract smaller words from within the stimuli and may indeed have resorted to a strategy based on phonemic sequencing only. In future experiments, it would be desirable to vary the materials so that the target is not in a fixed serial position and to use consonantal sequences which are demonstrably well-formed.

THE EXPERIMENTAL STUDY

Our experimental method, as just discussed, follows that of Treiman (1983) but differs by insuring that subjects both perceived the inputs as single words and produced single words as outputs. After a training phase in which the infixation is modeled using simple monosyllables, and practiced with feedback, there is a test phase in which the infixation is extended without feedback to more complex forms. In order to ensure the interpretability of the test phase, a number of controls are used.

First, to reinforce the basic pattern and verify that it continues to be applied, the test phase in all experiments below included novel examples of the same type as provided in the models.

(25) "boy" + əl → bəlɔy
"big" + əɪ → bəɪɪg
"patch" +ək → pəkæʧ

The experiments below included between 20% and 33% of such examples.

Second, in order to minimize effects of orthography, the base forms are presented to the subject auditorily using a stimulus tape. They reply orally, and their replies are phonetically transcribed. Third, digraph control words are included in the test materials in order to screen for orthographically based strategies. For example, if "ch" in "chimp" is broken into a /k/ and a /h/, the subject is obviously using an orthographically based response strategy. Third, subjects were carefully screened to ensure that they were monolingual in English. This was done out of deference to results by Cutler, Mehler, Norris, and Segui (1986), showing that even extremely fluent bilinguals show effects of the prosodic structure of their preferred language in processing their less preferred language.

About 25% of the subject pool (recruited by advertising at Northwestern University for native speakers of English) had to be eliminated because of fluency in another language.

In our experiments, five examples of the base pattern were initially provided. The training phase could have as many as 15 trials; it was terminated when subjects had produced eight correct forms in a row. The basic forms of the infixation games are extremely trivial and almost all subjects are able to produce the first eight training forms correctly. Despite success in the training phase, one subject was eliminated because he made only two out of 10 correct responses on the reinforcement words included in the test phase; no other subject made more than a single error on these words.

All stimuli in our experiments were reasonably familiar existing words of English. Existing words were used in preference to nonsense stimuli in order to ensure that subjects understood and conceptualized the stress patterns, a critical factor in two of the experiments. No candidate outputs were English words; in addition, no candidate outputs were analyzable as morphologically complex forms consisting of an existing English affix attached to a nonexistent stem. Candidate outputs were carefully examined for phonotactic violations, and for all stimuli used, all candidate outputs for infixation at or near the beginning of the word are admissible monomorphemic words of English. As an independent authority on allowable medial clusters, we used the highly conservative inventory in Lamontagne (1993), which is based on exhaustive study of an on-line dictionary. In addition, the experimental design ensured that no candidate output had two consonants of the same place of articulation separated by a single phoneme. This precaution was taken because of recent findings that such combinations, though attested in some words, are not only statistically under-represented (as discussed above), but are also productively avoided (Bybee & Slobin, 1982; Berkley, 1994a,b; Pierrehumbert, 1994b).

The numerous constraints on the output forms, in combination with the fact that the lexicon includes only a sparse representation of the set of phonotactically possible words, made it impossible to control for stimulus word frequency in our experiments. However, possible frequency effects of the candidate response forms are controlled for, since possible responses were not actual words and therefore have zero frequency.

Experiment 1

Methods. Experiment 1 investigated the behavior of the clusters /st/, /sl/, /pl/, /pɹ/, and /bɹ/ under insertion of a schwa-consonant infix. Subjects were trained using a schwa-r infix with monosyllabic base forms. The models are shown in (26):

(26)	"big"	bə ɹ ɪ g
	"damp"	d ə ɹ æ m p
	"sand"	s ə ɹ æ n d
	"fun"	f ə ɹ ʌ n
	"sift"	s ə ɹ ɪ f t

The model results were pronounced with a completely unstressed syllable at the beginning of the word, containing a reduced vowel. This is in contrast to experiments described in Treiman (1983), and Fowler et al. (1993), in which some outcomes are transcribed with full rather than reduced vowels in the syllables described as unstressed. In the linguistics literature, such syllables would be characterized as having secondary stress.

The materials in the test phase were constructed from a list of 96 words which varied the complexity and identity of the initial cluster, and also whether the base form was monosyllabic or disyllabic. Computer searches of an on-line dictionary were used to find words exhibiting near-minimal differences, as shown in (27) for /st/ test and control words, and in (28) for the /bɹ/ test and control words.

(27)	stub	tub	stubby	tubby
	state	date	station	nation
	stew	dew	steward	sewer
	stock	dock	stocking	docking

(28)	bran	ran	brandy	handy
	brig	rig	brigand	legend
	brisk	wrist	brisket	biscuit
	brook	rung	brooklyn	rookie

In addition to 80 such words which exhibited or controlled for one of the five clusters of interest, a similar set of 16 words involving digraphs rather than phonemically complex onsets was included, as discussed above.

(29)	chimp	tim	chamber	timber
	thumb	hum	thunder	hinder
	chat	hat	cheddar	header
	thirst	hair	thirty	dirty

We eliminated responses by the single subject who split a digraph into two corresponding phonemes (e.g. producing /kəlhɪmp/ rather than /ʧəlɪmp/ for "chimp").

In view of the fact that the materials exhibited minimal differences which might be conspicuous to the subjects, the total word set was then split to create two versions of the test. Each version was balanced for all experimental factors, but included only words which differed in at least two respects. For example, version A of the experiment included the words "stub" and "tubby" separated as far as possible in the randomization, while version B included "tub" and "stubby" similarly separated in the randomization. As a consequence of the split design, each subject answered only 48 test questions. There were 10 subjects for each version, or 20 altogether.

In the test, the infixes /əl/, /ək/ and /ət/ were used. These infixes were selected so as to permit the phonotactic requirements discussed above to be met. Each new infix was modeled with five monosyllabic words with simple onsets before the set of 16 test items for that infix was presented. The infix /əl/ was used for the /st/ word set and the digraph word set. The infix /ək/ was used for the /sl/ and /pl/ word sets. The infix /ət/ was used

TABLE 1

Responses in Experiment 1 to stimuli with onset clusters: Split and intact clusters (by number and percent) for each cluster type.

	st		sl		pl		bɹ		pɹ	
	n	%	*n*	%	*n*	%	*n*	%	*n*	%
Splits	5	6.25	18	22.5	19	23.75	12	15.0	12	15.0
Intacts	74	92.50	56	70.0	57	71.25	56	70.0	67	83.75

for the /bɹ/ and /pɹ/ word sets. Thus (using single words to represent classes of words), the experiment presented subjects with quandaries of the following types:

(30)	boy:	bəloy::	stub:	səltʌb? stəlʌb?
	patch:	pəkæʧ ::	planet:	pəklænət? pləkænət? plænəkət?
	bank:	bətænk ::	brook:	bətɹʊk? bɹətʊk?

Results. Essentially all insertions were made in the vicinity of the word onset. Only a single response out of 480 total responses for disyllabic words placed the infix before the rhyme of the last syllable. Thus, the possibility that subjects internalized a rule of inserting the infix before a final rhyme may be excluded, and results for monosyllabic and disyllabic base forms are combined.

Results for each cluster, combined across word length and across the 20 subjects, are presented in Table 1.

In this table, splits and intacts can sum to less than a hundred because of the sporadic occurrence of other types of responses. The additional type of most consequence consisted of responses in which a liquid in the onset cluster of the base was repeated both before and after the infix, as in the form "pləklænət"

As Table 1 shows, onset clusters were preserved more than they were split (at $p < .005$ by a one-tailed Wilcoxon test). This point is reinforced by Table 2 which shows how many subjects preserved how many of the clusters. The last column in this table gives significance levels for each subject's propensity to split or retain the clusters. The test used is a binomial test (the only test applicable to data for individuals).[1]

[1] The Wilcoxon *T*-test was used for the statistical analyses of the data in the experiments. This test is the nonparametric counterpart to the correlated or repeated measures *t*-test. It was used because we discovered both non-neglible skew (−1, 49 for experiment 1) and non-neglible variability amongst the subjects (see Table 2), thence the assumptions of the *t*-test are not fully met. A reviewer has requested that we also compute *t*-tests for the data from the experiments 1 and 3, and we have done so. All results reported as significant by a Wilcoxon *T*-test are also significant by the *t*-test.

TABLE 2

Subject by subject tendency to split clusters in Experiment 1: number, percentage, and statistical significance

No. of subjects	*No. of split clusters*	*% split clusters*	*tendency*	*significance (binomial test)*
12	0	0	retain	< .001
1	2	10	retain	.002
1	3	15	retain	.046
1	4	20	none	n.s.
1	5	25	none	n.s.
1	8	40	none	n.s.
1	11	55	none	n.s.
1	15	75	split	.018
1	18	90	split	< .001

Although onset clusters were retained more than they were split, they were split much more than previously reported. This facts demonstrates the great importance of output phonotactics. Compare the mean percentage of splits in our results, namely 16.5, to the mean in Treiman (1983), .8 . The cluster /st/ split the least, and the clusters /sl/ and /pl/ split the most. The /st/-/sl/ difference and the /st/-/pl/ difference are both significant at $p \leq .05$ by a two-tailed Wilcoxon test. The intermediate behavior of the /Cɹ/ clusters is not significantly different from that of either /st/ or the /Cl/ clusters. The interpretation of the results on /st/ will be taken up in the last section.

Experiment 2

Experiment 2 addressed the possibility that the preferred split point in monosyllabic words is conceptualized as being at the onset of the head (or most stressed) vowel. If this were the case, then noninitial stress should show a tendency to attract the infix location away from the beginning of the base word.

Since American English does not permit words to begin in two completely unstressed syllables, the infix in this experiment was a single phoneme, /ɹ/. Using a VC infix would have forced the subjects in some cases to either produce two unstressed syllables in a row, or readjust the stress features of the base form. The models in the experiment were:

(31)	"bin"	bɹ ɪ n
	"tag"	tɹæg
	"pill"	pɹ ɪ l
	"take"	t ɹeyk
	"golf"	gɹɔlf

Test materials were constructed by finding 16 triplets of words related as illustrated in (32); for each monosyllabic control, two highly similar test words were found which differed in stress pattern, one having main stress on the first syllable, and the other having main stress on the second syllable following an initial syllable which was completely unstressed (produced as a schwa on the stimulus tape).

(32)	deep	depot	depend
	tube	tuba	toboggan
	foot	fatal	fatigue

Note that all disyllabic words can accept an /ɹ/ infix into either the first or the second syllable. Therefore, the quandary for the subjects is:

(33) "bin": bɹɪn :: "tuba": tɹubə? tubɹə?
"toboggan": tɹəbɔgən? təbɹɔgən?

Words were randomized so as to maximally separate related forms and to evenly distribute base words of different stress patterns and lengths. There were 10 subjects for the experiment.

All 10 subjects without exception placed the infix after the first consonant of the word. This was the case for both stress patterns. The preference for placing the infix after the first consonant (as compared to other locations) was, as is obvious, statistically significant.

Experiment 3

Methods. Experiment 3 expanded on the design of Experiment 2 by including vowel-initial as well as consonant-initial words. The instructions and models were identical to those in Experiment 2. Ten of the word triplets used to construct the test phase of Experiment 2 were expanded to quintuplets by finding two vowel-initial words which were as similar as possible and which exhibited the stress contrast at issue. Examples are shown in (34):

(34)	pout	putty	potato	opposite	opinion
	cob	cabin	caboose	occasion	echo
	bet	bottom	battalion	ebony	about
	bike	bacon	bikini	abacus	abandon

For words with an initial-stressed vowel, only words with lax open vowels were used. This was done so that the output constraints would not rule out a possible generalization by the subjects to the effect that the /ɹ/ should be inserted after the first phoneme. A small difficulty arises because, in many dialects, some vocalic distinctions are collapsed before /ɹ/; for example, for most American speakers, the mid and low lax front vowels are not distinguished before /ɹ/. A number of our subjects inserted /ɹ/ after the vowel without exhibiting any discomfort about this neutralization, see below. Since vowel-initial words are somewhat exceptional in English, it was necessary to permit considerable latitude in other particulars of the words.

In summary, Experiment 3 presents the subjects with the following quandaries:

(35) "bin": bɹɪn ::	"bacon":	bɹeykən?	beykɹən?	
	"bikini":	bɹəkinɪ?	bəkɹinɪ?	
	"abacus":	ɹæbəkəs?	æɹbəkəs?	æbɹəkəs?
	"abandon":	ɹəbændən?	əɹbændən?	əbɹændən?

Results. Results of Experiment 3 are tabulated in table 3.

There was a striking contrast between the behavior of consonant-initial words and vowel initial words. The middle response category — /ɹ/ after the first vowel — was used only for vowel-initial words. (This is not surprising, because as (35) suggests, the experimental design did not anticipate post-vocalic insertions in consonant-initial words, and some such words would have been illicit.) More significantly, for consonant-initial words, the first available prevocalic infixation site was strongly preferred; for vowel-initial words, either the first vowel or the second could provide a locus for prevocalic infixations. The difference between the behavior of vowel-initial and consonant-initial stems is significant at $p \ll .001$ by a Chi-square test.

Secondly, stress did have an effect in this experiment, but the effect was a somewhat subtle one. For words with stress on the second syllable, infixation before the second vowel was preferred to affixation before the first vowel (39.5% vs. 25.9% of total responses). However, when the stress was on the first syllable, infixation before the second vowel was only very slightly preferred to affixation before the first vowel (33.6% vs. 30.5% of total responses). Hence, stress influenced the extent of the preference for infixation before the second vowel. To establish the statistical significance of this observation, a Wilcoxon test was carried out on the strength of the preference for placing the affix before the second vowel (as against initial position) for words with second syllable stress as against those with first syllable stress. Out of 22 subjects, 12 subjects showed differences of various amounts in the direction described, 9 subjects showed no difference, and only one subject had a difference in the opposite direction (placing the infix before the second vowel more often when it was not stressed), $p < .01$ by the Wilcoxon test.

The comparable calculation was also carried out for consonant-initial words. Although words with the infix inserted before the second vowel were in the distinct minority, nonetheless seven subjects showed more of a tendency to produce such responses when the second syllable was stressed than when the first syllable was stressed. The rest never placed the affix before the second vowel. As a result, the effect of stress on this word set proved significant at $p = .01$ by the Wilcoxon test.

The consonant initial words were a subset of those used in Experiment 2, but they behaved differently. A plausible hypothesis is that the variable placement of the infix in the vowel-initial words influenced the strategy for the consonant-initial words. In order to evaluate this hypothesis, the sequence of responses for the seven subjects who produced responses of the /bəkɹinɪ/ type was examined. For four subjects, the /bəkɹinɪ/ pattern

TABLE 3.
Location of /ɹ/ insertion in Experiment 3. (Number and percentage of responses counts out of 220 total)

	Location of /ɹ/:							
	before V1		*after V1*		*before V2*		*Other*	
Word type	*n*	*%*	*n*	*%*	*n*	*%*	*n*	*%*
C'V..	216	98.2	0	0	4	1.8	0	0
(bacon)	(bɹeykən)		(beyɹkən)		(beykɹən)			
CVC'V..	190	86.4	0	0	27	12.3	3	1.4
(bikini)	(bɹəkinɪ)		(bəɹkinɪ)		(bəkɹinɪ)			
'V..	67	30.5	71	32.3	74	33.6	8	3.6
(abacus)	(ɹæbəkəs)		(æɹbəkəs)		(æbɹəkəs)			
VC'V..	57	25.9	72	32.7	87	39.5	4	1.9
(abandon)	(ɹəbændən)		(əɹbændən)		(əbɹændən)			

only developed after the comparable pattern for vowel-initial words was established. Three subjects produced the response /dəfɹit/ as the very first item in the test phase; of these, two subjects produced exceptionally stress-tropic responses in general. Thus, it appears that a transfer effect may have played a role, and furthermore that subjects differ greatly in the importance they place on stress.

GENERAL DISCUSSION

The best onset/rhyme theory

There are many possible theoretical interpretations of the finding that the preferred split point in monosyllabic words is at the boundary between the classical onset and the classical rhyme. By bringing a greater diversity of materials to bear, we are now in a position to consider whether novel word games do or do not support the concepts of the onset and/or the rhyme as phonological constituents. We begin by developing the characterization of the patterns observed which is most favorable to the onset/rhyme theory.

Interpretation of novel word games as supporting the onset and rhyme depends, as noted above, on the assumption that a structural analysis of the base form is decisive in constructing the game form. This assumption may be fleshed out into the detailed alternatives listed in below in (36):

(36) Possible derivational "game rules" for infixation into a monosyllable:

Infix before a final rhyme.
Infix at head position.
Infix after an initial onset.

Infixation before a final rhyme may be eliminated in our experiments because our subjects placed the infix into the first rather than the second syllable of disyllabic words. Infixation at head position is ruled out by Experiment 2, where subjects placed the infix into the first syllable rather than the stressed syllable of words with noninitial stress (caboose → /kɹəbus/). Infixation after an initial onset broadly covers the results of Experiments 1 and 2, though it makes no provision for the split onsets which did occur. In the absence of additional assumptions, it does not make any provision for vowel initial words, which have no initial onset. Thus it fails to explain why the infix in these words was always placed near the beginning, and why stress had the effect it did.

Since none of the possibilities in (36) covers the data, we consider, at the expense of some strain with current theoretical understanding, the following additional alternatives:

(37) Infix before the first rhyme.
Infix after the first onset.

Infixation before the first rhyme predicts that "adobe" would become /ɹədobi/; though this response type did occur, it was not the predominant one. Infixation after the first onset does indeed describe the dominant pattern in all three experiments (plant → /pləkænt/; caboose → /kɹəbus/; adobe → /ədɹobi/; abacus → /æbɹəkəs/). This formulation of the game rule thus appears to be the one which is most advantageous for classical onset/rhyme theory.

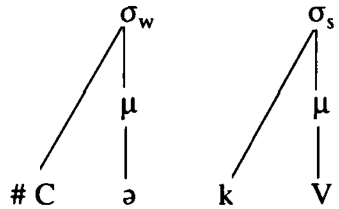
A better alternative

However, this interpretation is not completely satisfactory. A rule of infixation after the first onset fails to explain why some onsets were more readily split than others in Experiment 1. It does not explain why the results for vowel-initial words were so much more variable than those for consonant-initial words. Lastly, it sheds no light on the role of stress in Experiment 3.

The alternative we propose is as follows: In the novel word games, subjects did not acquire a rule for manipulating the input, but rather a target format or template for the result. These templates were extremely detailed, reflecting only the most conservative generalizations of the model forms. That is, the target templates encode everything that is true of examples already encountered. As a result of this level of detail, they are in fact overly specific for the novel cases; when different types of base forms are introduced, not all aspects of the target output format can actually be achieved. In order to produce the extended patterns, subjects pick the best possible match to the output format. In establishing what is the best possible match, some aspects of the template are more important than others. Furthermore, subjects vary in the importance they place on different factors and the experience they gain in the course of the test phase of the experiment can lead to incremental modification of the target formats.

Experiment 1 involved four VC infixes (/əɹ/ in the game models; /əl/, /ək/, /ət/ in the three parts of the test phase). The models all were monosyllables beginning in a single consonant; the post-vocalic regions varied. We propose output template (37) as summarizing what was true of the model outputs involving the infix /ək/; the templates for the other infixes would be analogous.

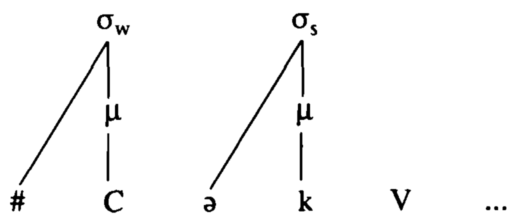
(38)



That is, the infix /ək/ "wants to be" a heterosyllabic sequence, with the V standing as the reduced vowel in a word initial unstressed CV syllable, and the /k/ being both prevocalic and at the start of the main stressed syllable of the word.

When the base form begins in Cl or Cr, the two choices both deviate from the template, as exemplified in figure (39).

(39)



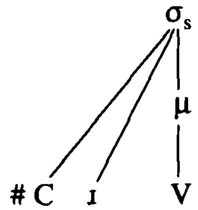
(a)	p l	ə	k	æ	n	ə	t
(b)	p	ə	kl	æ	n	ə	t

(a) deviates by virtue of having an extra consonant at the beginning of the word. (b) deviates because the consonant of the infix is not intervocalic, but appears instead before a sonorant consonant. However, it is still the first element in a stressed syllable as desired. The fact that both outcomes are possible indicates that one of these deviations is not overwhelmingly worse than the other. However, most subjects select (39a) over (b). 39(a) has an extra consonant at the edge, whereas in (b) there is an extra consonant in the middle of the form. As discussed above, there is a widespread tendency for languages to tolerate extra consonants at the word edge and we suggest that this is the reason that subjects in general prefer (a) to (b).

The situation is somewhat different when attempting /əl/ infixation into a base form beginning in /st/. Iŋ this case, forms which preserve the /st/ sequence (e.g. stub → /stəlʌb/) fall under case (a) above, displaying only an extra consonant at the beginning of the word. Furthermore, this extra consonant, /s/, is precisely the one which can be "extra" in the language in general, violating sonority sequencing at the beginning of words and providing the third consonant of triconsonantal onsets. Attempting to break up the /st/ cluster, in contrast, creates a more severe violation of the target output. The /l/ must be syllabified in the first syllable, with the two results that it does not begin the second, stressed syllable, and that the first syllable, though unstressed, is heavy. "Sultana" is the only word which has this form in the Collins dictionary; in general, the only heavy reduced initial syllables in English are a particular set of prefixes such as "ob" and "ab" (see Chomsky & Halle, 1968; Fudge, 1984). Thus, the paucity of splits of /st/ can be explained by the resulting problems with the output. The output oriented approach is critical to understanding why /st/ was overwhelmingly preserved in our results, whereas in Fowler et al. (1993) it, on the contrary, showed only a weak tendency to move as a unit.

Turning now to Experiment 2, the relevant template for the /ɹ/ infix is:

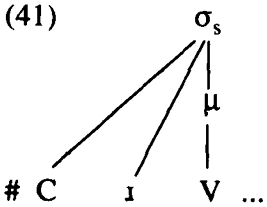
(40)



For stress-initial words such as "cabbage", the specifications of this template can be entirely achieved. The actual outcome for "caboose", namely /kɹəbus/, involves a mismatch on the stress feature for the vowel. The alternative possibility "caboose → /kəbɹus/" involves a mismatch at the left edge of the template, since there are two extraneous segments, comprising an entire syllable, to the left of the ideal insertion site. In the other alternative, /kəɹbus/, the /ɹ/ is closer to the left edge, (though not as close as it might be); at the same time, the syllabic position and segmental context of the /ɹ/ are completely incorrect. From the uniformity of the experimental results, we infer that the stress mismatch is not as bad as the other mismatches. The tolerance of stress mismatches might be related to the variability of stress in morphologically related forms in English, as illustrated in pairs such as "Plato" "platonic", and "ocean", "oceanic". Note that in the resulting output, the stress pattern of the base form is preserved. That is, it takes priority over the stress specification in the output template, presenting a broad parallel to results by Steriade and by Inkelas discussed above.

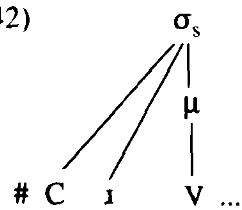
For Experiment 3, let us consider first the vowel-initial base forms, such as "adobe" and "abacus". For these forms, none of the candidate outcomes match very well, as shown in (41) and (42).

(41)



ə d ɹ o b.i
ɹ ə d o b i
ə ɹ d o b i

(42)



æ b ɹ ə k ə s
ɹ æ b ə k ə s
æ ɹ b ə k ə s

Neglecting stress momentarily, we observe that the first candidate in each set has an extra segment at the beginning of the form; however, this stray segment comprises a syllable, and thus presumably represents a worse deviation from the desired output than the stray consonants in Experiment 1. The second candidate is deviant because it lacks an initial consonant which should be present. The third has no extra segments, but shows severe mismatches in the type and prosodic position of the segments around the /ɹ/. The variability in the outcomes is explained by the fact that all solutions to the template mapping involve a serious violation of the original template.

Comparing the candidates for "adobe" and "abacus" it is clear that the first candidate is better for "adobe" than for "abacus". In /ədɹobi/ the /ɹ/ is in the desired position relative to the stress, whereas in /æbɹəkəs/ it is not. When the /ɹ/ is placed in absolute initial position (the second pair of candidates), the stress in the template, on the contrary, is respected for stems with initial stress but not for stems with stress on the second syllable. These observations explain the effects of stress observed in the data — /ɹæbəkəs/ competes better with /æbɹəkəs/ than /ɹədobi/ does with /ədɹobi/. Note that even when the conflict between the base form stress and the template stress plays a role in determining the outcome, it is the base form stress that is actually produced. In this respect, the data from Experiment 3 parallel those of Experiment 2.

The approach, then, is immediately successful in explicating the distribution of responses in the first two rows. Two questions remain. One is why any subjects produced responses such as /əɹdobi/, which differs so substantially from the target template. The other is why in Experiment 3, unlike Experiment 2, noninitial stress in words beginning with a consonant (such as "caboose") sometimes attracted the infix. The answer to both questions may lie in restructuring of the target template during the test phase.

Responses of the type /əɹdobi/, in which the /ɹ/ is inserted in coda position, suggest the application of a more general template than that shown in (40), specifically a template in which the infix is placed after the first phoneme regardless of its type or syllabic position.

(43) # X ɹ

Subjects who adopted this strategy may have been driven to do so by a sense that the alternatives (/ɹədobi/, /ədɹobi/, etc.) were simply too remote from their first impression of the output format.

Responses of the type /kəbɹus/ are distinguished from the basic r-infixation template of Experiments 2 and 3 by having two extraneous segments, or an entire extraneous syllable, at the beginning of the word. However, the output template for the experiment is not necessarily frozen at the end of the training phase, but may also be affected by outputs produced during the test phase. In Experiment 3 (unlike Experiment 2) the inclusion of vowel-initial words leads subjects to produce words such as /ədɹobi/, in which the output template had already been expanded by an initial syllabic element. Such outcomes may have led subjects to relax or expand the original target template. The template thus expanded would yield a better match than the basic template to forms such as /kəbɹus/.[2] Compared to the expanded template, /kəbɹus/ has only a single extraneous consonant at the beginning.

Relation to phonological theory

The description just presented is cast in terms of an output template for the infixes in the experiment. In this regard, it conforms to the constraint-oriented approach of current theoretical work, as outlined in Section 2. As argued in the previous section, even the best derivational approach to the experimental results is not able to support an equally detailed exegesis. However, in Experiments 2 and 3, the base form stress was transferred to the output even in violation of details of the output template. Thus, the experimental paradigm does show some sensitivity to the prosodic structure of the base form. But, it does not provide specific support for the onset-rhyme constituency posited in (1) of the introduction.

The results show that prosodic position matters; they thus reinforce a general lesson of work on speech production from Fromkin (1973) onwards. Specifically, the output targets for the infixes include specifications about their position in the prosodic structure with reference to the left edge and to the head. Therefore some means for formalizing prosodic position is required. Moraic theory has been adopted here for the sake of specificity. But the results are merely consistent with moraic theory; they do not support moraic theory over all other theories. For example, the posited templates could easily be recast into the flat syllable theory of Clements and Keyser (1983). Hierarchical models of the syllable, such as the onset-rhyme model, are more complex than simple models because they have the same terminal elements but posit more structure. Thus, Occam's razor is against them. By removing one line of evidence for the most articulated hierarchical models, the present results support flatter models.

The output constraints posited are extremely specific. In fact they are excessively specific; subjects were required to produce forms in which the constraints could not be met in every detail while still preserving the phoneme string of the base forms. In order to respond they violated some of the constraints. The mere fact of constraint violation is theoretically unproblematic, since all well-articulated phonological theories provide technical support of some kind for principles with exceptions. In the framework of Chomsky and Halle (1968), the abstract representations of exceptional forms include diacritics which block the application of rules which would otherwise apply. In Variationist Theory, probabilities assigned to rules have the result that they sometimes apply and sometimes do not (see e.g. Guy, 1991a,b). In Lexical Phonology, the "Strict Cycle" ensures that exceptional aspects of lexical representations are preserved through the cyclic component of the grammar and lexical exceptions to rules are also countenanced (Kiparsky, 1985). In Declarative Phonology (Coleman, 1992; Scobbie, 1993), logical disjunctions and defaults are used for constraints which are true of some but not all surface forms. In Optimality Theory, constraint ranking adjudicates situations in which it is not possible to meet all constraints. This technical device has recently drawn attention in the field to the violability of constraints and has led to many descriptions proposing extremely general but often violated (e.g. low priority) constraints.

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[2] It should be noted that these subjects produced the first response of this type before encountering any vowel-initial words in the test set. Evidently subject three viewed the infix in the models as aligned to the head vowel rather than to the left edge of the word. In general it is not surprising to find inter-subject variation since people differ considerably in the cognitive importance they assign to stress, as shown for example in Nakatani et al. (1981).

The approaches just mentioned differ considerably, however, in their theoretical treatment of the violable regularities and hence in the kinds violations they are able to handle. The constraints proposed here are both stochastic and formative-specific, since the new infixes in the experiments have the phonological status of new formatives. Optimality Theory as described in Prince and Smolensky (in press) and McCarthy and Prince (1994) provides no support for such constraints. Constraints are claimed to be universal (or available in all languages) and nonstochastic, with languages differing only in the ordering of the constraints. Furthermore, Optimality Theory draws a strong distinction between the grammar and the lexicon, with constraints residing in the grammar and not in the lexicon.[3] Declarative Phonology, in contrast, draws no strong distinction between constraints and lexical items; constraints are represented in exactly the same way as lexical items, as pieces of phonological structure. The only difference is that the constraints are more general. Since they describe groups of words rather than individual words, they include shared properties of the words they describe, and omit the properties which differ. This approach is well suited to the present situation, provided that it is extended so that constraints can be stochastic instead of categorical. Hence, we take results of the type we have presented here as an argument that constraints and lexical items should be represented in the same way.

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Editors' note: A reply to this article, by Recbecca Treiman and Brett Kessler, will appear in the next issue of the Journal.

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[3] See Berkley, 1994b for the difficulty this separation raises in another connection, namely constraints on place of articulation within and across morpheme boundaries.

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