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The sequential cuing effect in speech production

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Abstract

How are the sounds of words represented in plans for speech production? In Experiment 1, subjects produced sequences of four CVCs as many times as possible in 8 s. We varied the number of repetitions of the initial consonant, vowel, final consonant, CV, rhyme, and whole CVC each sequence required, and measured subjects' speaking rate. Subjects produced more CVCs when the final consonant or whole word was repeated, but were slowed when only initial sounds or CVs were repeated. Two other experiments replicate the location-based effects and extended them to bisyllabic words. We attribute the locational effects to competition between words that are formally similar, and specifically, to competition between discrepant phonemes in the two words to occupy a particular wordframe position. The fact that only discrepant initial, but not final sounds slow production suggests that phonemes are activated sequentially, from left to right.

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1. Introduction

Speaking is an activity that requires planning. Theories of language production hold that speech must be planned at several levels, some more closely tied to the meaning of the utterance, and others to its form (Fromkin, 1971; Garrett, 1975; Levelt, 1989). Here we deal with planning the form of an utterance, and the question of what structures must be represented to produce simple words.

Linguistic analyses support at least three levels of structure inside words, including syllables, phonemes, and phonological features. In addition, many accounts of syllable structure recognize one or more levels between the

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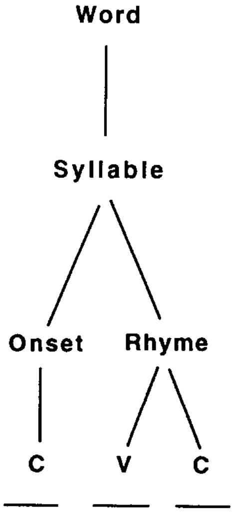

Fig. 1. A standard model of word structure.

syllable and the phoneme. A standard model of word structure is shown in Fig. 1. According to this model, words consist of syllables, and syllables consist of an onset and a rhyme. The rhyme has a nucleus and a coda, each of which can be made up of multiple phonemes.

In many accounts, the rhyme has a special status because it contains the only obligatory part of the syllable, the nucleus. Rhyme structure also partially determines metrical structure (Levin, 1985). In languages that have a syllable–weight distinction such as English, syllables contrast in weight depending on the content of the rhyme (Hayes, 1989; Hyman, 1985; McCarthy & Prince, 1986, 1990). Syllable weight, in turn, is one of the factors that determines where stress will be assigned.

Both spontaneous speech errors and experimental evidence suggest that syllables, phonemes and features must be represented to produce speech (Fromkin, 1971; see Levelt, 1989 for a review). Most phonological speech errors are movements of single phonemes, suggesting that phonemes are part of the plan. The evidence for syllables and features is less straightforward. Slips of whole syllables are rare, but syllable structure determines which phonemes will interact, namely, those from identical positions of nearby words or syllables (MacKay, 1970; Shattuck-Hufnagel, 1979). Likewise, unambiguous slips of individual features are rare (Shattuck-Hufnagel & Klatt, 1979) but phonemes with shared features are more likely to slip (e.g., MacKay, 1970).

There is also evidence supporting the use of the onset and rhyme. Speech-error evidence shows a double dissociation between these two units. The most common phonological errors are movements of an initial consonant or cluster, leaving the rhyme intact (Garrett, 1975; MacKay, 1970, 1974; Shattuck-Hufnagel, 1986, 1987, 1992; Stemberger, 1983). When a consonant and a vowel both slip, the transposed material is usually a rhyme rather than a CV (MacKay, 1972; Nooteboom, 1969; Shattuck-Hufnagel, 1983, 1986). Experiments that require subjects to intentionally exchange components of words confirm this pattern (Fowler, 1987; Fowler, Treiman, & Gross, 1993; Treiman, 1983, 1986). Subjects in these experiments tend to break syllables between the onset and the rhyme.

The structure of the vocabulary provides a final argument for the rhyme. Across languages, the content of the rhyme tends to be more restricted than the content of other parts of the syllable (Goldsmith, 1990) so that what follows a vowel is more predictable than what precedes it. English, for example, has fewer VC combinations than CVs (Dell, Juliano, & Govindjee, 1993). This redundancy makes the rhyme a credible planning unit. An alternative view (Iverson & Wheeler, 1989) in which the CV and not the rhyme is represented has much less support.

The experiments reported here test hypotheses about the units represented in plans to produce simple words. The possible planning units include the syllable, the CV, the rhyme, and phonemes that constitute the onset, nucleus, and coda.[1] The experiments are partly motivated by an *editing* view of speech planning, in which a new plan can reuse part of an earlier one if aspects of the sequence are repeated. This view, taken from the literature on the planning of movement sequences, is adapted to speech production (Rosenbaum, Weber, Hazelet, & Hindorff, 1986; Sternberg, Monsell, Knoll, & Wright, 1978). In the editing view, a plan is a schema with variables to which values are assigned (Rosenbaum, 1987; Rosenbaum, Inhoff, & Gordon, 1984). In the case of the production of a CVC such as "pick" for example, the potential variables include the initial consonant (C_i), vowel (V), and final consonant (C_f) and larger units such as the rhyme or whole CVC. The values assigned to these variables are particular phonemes or particular higher-level units. For example, a plan to produce the word PICK might specify CVC = /pIk/, rhyme = /Ik/, C_i = /p/, V = /I/, and C_f = /k/. If the next word repeats some assignments, then part of the plan can be reused, as for example if the next word is TICK. The editing view predicts a benefit for repeating value assignments to variables actually used in the plan. By manipulating which aspects of words are repeated, we may discover which variables are represented. If, for example, the plan represents the CV and not the rhyme, then it should be easier to produce a sequence that repeats the CV (PICK PIN) rather than the rhyme (PICK TICK).

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[1] We do not specifically test the role of features, but the potential effects of shared features are controlled for by permuting assignments of particular phonemes to initial and final positions in the CVC.

The editing view of planning predicts benefits for repeating units, but empirical findings suggest that there may also be costs. Studies of natural speech errors and of tongue-twisters show that repeating sounds often leads to errors (Butterworth & Whittaker, 1980; Kupin, 1979). Initial consonant exchanges occur more often in the context of an identical vowel, such as saying *heft lemisphere* for *left hemisphere* (Dell, 1984; MacKay, 1970). Inhibitory effects on response time have been found as well. Naming or lexical decision is often slowed when the target is primed by a word that is formally similar but not identical (e.g., Colombo, 1986; Levelt et al., 1991; Lupker & Colombo, 1990; O'Seaghdha, Dell, Peterson & Juliano, 1992; Peterson, 1991; see also Bock, 1987). In sum, inhibitory as well as facilitative effects have been found when only parts of words are repeated.

A model designed to account for repetition costs as well as benefits is the *phonological competition model* (O'Seaghdha et al., 1992; Peterson, 1991; Peterson, Dell, & O'Seaghdha, 1989). The structure of this model is illustrated in Fig. 2. The model is a network with nodes for words and phonemes, and connections between the nodes. When a word is to be spoken, its node is activated, and activation spreads downward to its component sounds. Each phoneme in the language is represented by a single node, so words that share phonemes connect to the same nodes. Activation is assumed to spread upward as well as downward in the network, so a target word also sends activation from its phonemes to nodes for other words that share sounds with the target. These words, in turn, send activation to nodes for their component sounds. Eventually, the most highly activated phonemes are selected and inserted into slots in a *phonological*

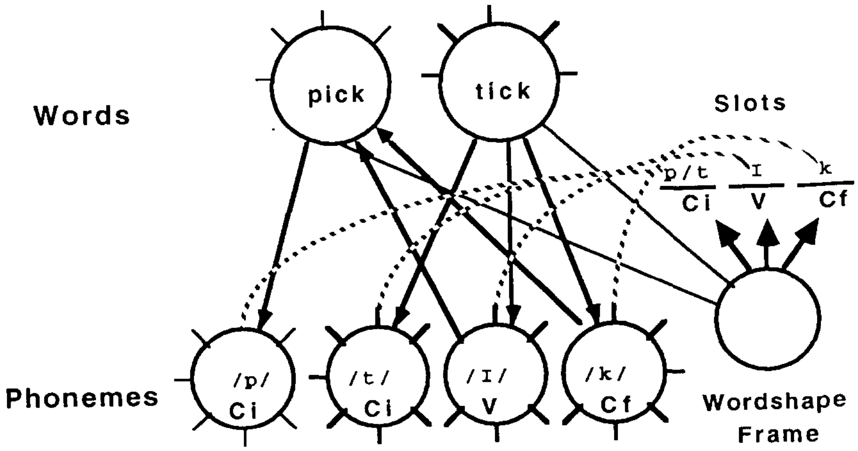

Fig. 2. Phonological competition model. The effect of having just produced *PICK* on the production of *TICK*.

frame, completing the production plan. The frame has several functions, but the most important of these is to specify the order of the word's sounds.

The model is an adaptation of spreading activation models of speech errors (e.g., Berg, 1988; Dell, 1986, 1988; Harley, 1984; MacKay, 1987; Martin, Weisberg, & Saffran, 1989; Stemberger, 1985, 1990) to account for response-time results in lexical priming paradigms. It predicts that repeating whole words will be beneficial, but that repeating only *parts* of words will slow production, compared to saying formally dissimilar words, when the words in question are frequent or very recently used. To understand this prediction, consider the effect of having just said PICK on the production of TICK. According to the model, all of the phonemes of TICK become active simultaneously. Activation spreads via shared phonemes in TICK to the node for PICK, which is more easily activated because of its recent use. This means that the node for /p/ also receives some activation, creating competition with /t/ to occupy the initial position. Cuing by shared phonemes leads to competition between discrepant phonemes and slows the encoding of TICK. If adjacent words are identical, as in PICK PICK, there is no competition, and the effect is instead a pure benefit due to reusing the same nodes. Because phonemes are activated simultaneously, the phonological competition model predicts that repeating *either* initial or final sounds without repeating the whole word will lead to competition, and thus a repetition cost. The simultaneous activation assumption is not entirely satisfying though, in that some data (Meyer, 1991) and other models (Dell et al., 1993; Houghton, 1990; MacKay, 1987) argue against it.

Our experiments examined the benefits and costs of repeating linguistic units using a *parameter remapping paradigm* (Rosenbaum et al., 1986). In this paradigm subjects produce sequences as many times as possible within a fixed time period, and speaking rate is measured. Subjects in the first experiment were given sequences of four CVC monosyllables. On each trial they repeated one of these sequences as many times as possible during an 8 s response interval. To test hypotheses about how CVCs are planned, we varied the frequency with which candidate planning units were repeated in the next CVC. The candidate units included initial consonants, vowels, final consonants, VCs, CVs, and entire CVCs. For example, one condition alternated the sounds of the CV (and therefore also the initial consonant and the CVC as a whole) but repeated the rhyme (e.g., PICK TICK PICK TICK). Another alternated the rhyme but repeated the CV (e.g., PICK PIN PICK PIN). In all, 27 conditions were tested, allowing us to draw inferences about which units control the variance in speaking rate.

Before going into details about the conditions, we can make some general predictions. The editing view predicts that repeating a unit should be beneficial compared to conditions in which the unit is not repeated, and that immediate repetition should be more beneficial than delayed repetition. Given this logic, it should be possible to identify planning units by measuring the repetition benefit associated with each candidate unit. Those with the greatest benefit would be considered the most basic units. Repetition frequencies of candidate units are often confounded with one another (e.g., repeating the rhyme also repeats the vowel and the final consonant), but multiple regression models can be used to partial out the contribution each factor makes to a model of speaking rate. At this point, we make no predictions about what the actual units are, only that by this account, they will be associated with repetition benefits.

Unlike the editing model, the phonological competition model predicts a benefit only for repeating the whole word, and a repetition *cost* for similar but nonidentical CVCs. It also predicts that this cost should be the same for shared initial or final sounds. Neither the phonological competition model nor the editing model makes assumptions or predictions about the role of units between the syllable and the phoneme (such as the rhyme or the CV), but the role of these and other candidate units will be tested under the two models.

EXPERIMENT 1

The materials were sequences of four monosyllabic CVC words, one sequence per trial. Subjects studied the sequence for 8 s before hearing warning tones and a response signal. They were to begin saying the sequence as soon as possible after hearing the response signal and to repeat the sequence as many times as possible before a final signal, 8 s later. The dependent measure was a measure of speaking rate called *production time*. Production time was obtained by dividing the response period by the number of CVCs produced on a given trial, and is the average time taken to produce a CVC. This measure was of primary interest because, presumably, remapping effects would arise in the online editing of a sequence for production.

To study online planning, we manipulated whether the sounds assigned to various units were either repeated or changed. To allow us to better track repetition effects, the immediacy and frequency of repetition were also varied. Three *repetition patterns* were used to assign sounds to the initial consonant (C_i), medial vowel (V), and final consonant (C_f) slots of each of the four CVCs of a response. The three patterns were an *AAAA* pattern, an *ABBA* pattern, and an *ABAB* pattern. The letters denote where the sounds in a particular slot changed across the four CVCs. In the *Immediate* repetition or AAAA pattern, sounds were repeated in each adjacent CVC. When the whole CVC followed this pattern, the result was a sequence like *PICK PICK PICK PICK*. According to the editing view, this sequence should be easy to say if CVC words are planning units. In the *Near* repetition or ABBA pattern, sounds were repeated in the adjacent CVC half of the time, on average.[2] When the whole CVC followed this pattern, the result was a sequence like *PICK TON TON PICK*. This sequence should be harder to produce, because value assignments must be changed. Finally, in the *Far* repetition or ABAB pattern, phonemes were not repeated in adjacent words at all. When all of the slots were assigned sounds using this pattern, a sequence like *PICK TON PICK TON* was the result. This condition should be more difficult than the others because values must be changed more often.

The three patterns determine how often a value assignment can be reused in the next CVC, but they are not only applied to whole CVCs. Instead, *each* pattern was applied independently to *each* of the slots in the phonological frame, in all possible combinations (3 slots by three patterns) yielding 27 different combinations, called *sequence conditions*. The full range of conditions is shown in Table 3. A sample sequence like *PICK PUN PUCK PIN* illustrates how the sequence conditions were created. In this sequence, the initial consonants follow the Immediate pattern (*/p/*__ */p/*__ */p/*__ */p/*__), the vowel follows the Near repetition pattern (_*/I/*_ _*/ʌ/*_ _ */ʌ/*_ _*/I/*_), and the final consonant the Far repetition pattern (__*/k/* __*/n/* __*/k/* __*/n/*). Applying repetition patterns to slots in all possible combinations across the design made it possible to test repetition effects for phonemes in the onset, nucleus, and coda positions, and to test effects of repeating larger units. To test repetition effects for suprasegmental units, the *same* pattern was applied to adjacent slots. In a sequence like *PICK TON TICK PUN*, for example, the initial consonants followed the Near repetition pattern (ABBA), but both the vowel and C_f followed the Far repetition pattern (ABAB), manipulating the *rhyme*. As a result, in addition to C_i, *V*, and C_f *patterns*, we can speak of *Rhyme*, *CV* and *CVC patterns* in the sequences.

For units larger than segments, there was one additional pattern. In the *PICK TON TICK PUN* example, the CV and CVC of the sequence followed an *ABCD* or *Nonrepetition* pattern, which should be the most difficult, by the editing view. In the Nonrepetition pattern, values were not repeated at all within a sequence. Comparisons of the Nonrepetition and Far repetition pattern were used to test whether repetition effects extended beyond immediate repetition. Because the materials used only CVCs, we were unable to compare effects of repeating segment-sized planning units with effects of repeating an onset, nucleus, or coda made up of multiple

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[2] Remember that subjects must repeat a sequence several times during a trial. A constituent that has been assigned sounds using an ABBA pattern was often produced as "A BB AA BB A . . ." (etc.). So, for example, the sequence *PICK TUCK TUCK PICK* might be produced as *PICK*, *TUCK TUCK*, *PICK PICK*, . . . (etc.), with a small pause between pairs of repeating CVCs. Sounds are repeated every second monosyllable throughout the trial. Immediate repetition of the sounds assigned to a unit in the next monosyllable occurs half of the time, on average, across the trial.

segments. Also, since only monosyllabic words were used in this experiment, we were unable to compare words and syllables as planning units.

2. Method

2.1. Subjects

Eight University of Illinois students served as subjects. Subjects were paid five dollars per hour. Each subject served in one practice session and eight test sessions on separate days, and each completed the full design.

2.2. Materials

Response strings consisted of sequences of four CVC monosyllabic words. One of two possible phonemes was assigned to each of the three positions in the CVC. These positions were called the C_i, V, and C_f slots, and corresponded to the onset, nucleus, and coda positions of the CVC. Sounds were assigned to the C_i, V, and C_f slots of four CVCs to create each sequence.

Three other *nonstructural* factors were incorporated into the design to ensure that sequence conditions were not confounded with effects of particular C_i and C_f values. First, two different *Phoneme Sets* were used. In the *ptkn-set* the C_i slot had a value of either /p/ or /t/, the V slot took an /I/ or an /ʌ/ (as in *TICK* or *TUCK*), and the C_f slot took either a /k/ or an /n/. In the *fdlr-set*, the C_i value was either /f/ or /d/, the vowel was either /i/ or /e/ (as in *FEEL* or *FAIL*), and the C_f was either /l/ or /r/. Subjects produced sequences like *DARE FEEL FAIR DEAL*, for example, as well as those like the *PICK TON TICK PUN* example above.[3] A given phoneme never occurred as both an initial and a final segment in a sequence. Table 1 shows the resulting set of 16 words used in the sequences.

A second nonstructural factor was called *Reversal*. The pair of phonemes designated as C_i segments was switched with the pair designated as C_f segments (e.g., "TICK" becomes "KIT"). Reversing the *DEAL DARE DALE DEAR* sequence yielded *LEAD RAID LAID REED* for instance. This added 16 monosyllables to the design, three of which were nonwords, as shown in Table 1. Finally, to increase the number of sequences, the *Order* of assignment of particular C_is, Vs, and C_fs to their respective slots was manipulated. The order factor determined which of the two possible sounds was assigned to a sequence first. Table 2 shows examples of all 8 Order conditions, holding other factors constant. The order factor was

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[3] Each phoneme set used either both tense or both lax vowels, so that whether or not the vowel was repeated in the sequence would not effect production time due to differences in intrinsic vowel length. Tense vowels tend to be intrinsically longer than lax vowels (Lehiste, 1970).

Table 1
CVC monosyllables used in response strings

Phoneme set	Reversal	
	Nonreversed	Reversed
1	TICK, TUCK, PICK, PUCK, TIN, TON, PIN, PUN	KIT, CUT, KIP, CUP, KNIT, NUT, NIP, NUP
2	DEAL, DALE, FEEL, FAIL, DEER, DARE, FEAR, FAIR	LEAD, LAID, LEAF, LAFE, REED, RAID, REEF, RAFE

crossed with the Phoneme Set and Reversal conditions, adding 8 factor levels to the design. The nonstructural factors contributed 2 (Phoneme Set) × 2 (Reversal) × 8 (Order) factor levels to the design.

2.3. Repetition patterns

Sounds were assigned to slots using one of three repetition patterns. These patterns determined where the phonemes for a particular slot would change across the four monosyllables in a response. Sounds were assigned to the C_i, V, and C_f slots in the CVCs using either an AAAA, an ABBA, or an ABAB pattern. These patterns were applied to the slots in all possible combinations, yielding 27 different sequence conditions. Examples of responses in each of the 27 conditions are given in Table 3, along with codes for the patterns of both segmental and suprasegmental units. Taking all of the factors into account, the total design was a 2 × 2 × 8 × 27 within-subjects factorial design with 864 distinct response strings.

2.4. Apparatus

Response strings and trial feedback were displayed to subjects on a Dell System 310 computer, which also generated auditory warning signals and

Table 2
Examples of levels of the order factor, holding assigment patterns constant

Order	Response sequence
1	TICK PUCK PICK TUCK
2	PICK TUCK TICK PUCK
3	TUCK PICK PUCK TICK
4	PUCK TICK TUCK PICK
5	TIN PUN PIN TON
6	PIN TON TIN PUN
7	TON PIN PUN TIN
8	PUN TIN TON PIN

Note: C_i pattern = ABBA, V pattern = ABAB, C_f pattern = AAAA; phoneme set = 2; reversal = nonreversed.

Table 3
Examples of responses for the 27 sequence conditions

Repetition pattern	AAAA = I (Immediate repetition) ABBA = N (Near repetition) ABAB = F (Far repetition) ABCD = NR (Nonrepetition)

Example of segments	Repetition pattern			Repetition pattern of larger constituents		
	C_i	V	C_f	CV	Rhyme	CVC
PICK PICK PICK PICK	I	I	I	I	I	I
PICK PIN PIN PICK	I	I	N	I	N	N
PICK PIN PICK PIN	I	I	F	I	F	F
PICK PUCK PUCK PICK	I	N	I	N	N	N
PICK PUN PUN PICK	I	N	N	N	N	N
PICK PUN PUCK PIN	I	N	F	N	NR	NR
PICK PUCK PICK PUCK	I	F	I	F	F	F
PICK PUN PIN PUCK	I	F	N	F	NR	NR
PICK PUN PICK PUN	I	F	F	F	F	F
PICK TICK TICK PICK	N	I	I	N	I	N
PICK TIN TIN PICK	N	I	N	N	N	N
PICK TIN TICK PIN	N	I	F	N	F	NR
PICK TUCK TUCK PICK	N	N	I	N	N	N
PICK TON TON PICK	N	N	N	N	N	N
PICK TON TUCK PIN	N	N	F	N	NR	NR
PICK TUCK TICK PUCK	N	F	I	NR	F	NR
PICK TON TIN PUCK	N	F	N	NR	NR	NR
PICK TON TICK PUN	N	F	F	NR	F	NR
PICK TICK PICK TICK	F	I	I	F	I	F
PICK TIN PIN TICK	F	I	N	F	N	NR
PICK TIN PICK TIN	F	I	F	F	F	F
PICK TUCK PUCK TICK	F	N	I	NR	N	NR
PICK TON PUN TICK	F	N	N	NR	N	NR
PICK TON PUCK TIN	F	N	F	NR	NR	NR
PICK TUCK PICK TUCK	F	F	I	F	F	F
PICK TON PIN TUCK	F	F	N	F	NR	NR
PICK TON PICK TON	F	F	F	F	F	F

response cues. A hardware voicekey was used to detect the onset of speech. Subjects' responses (and the auditory signals) were tape-recorded for later analysis.

2.5. Design and procedure

A master list consisting of all 864 response strings was created. To reduce effects of articulatory tiring, the Phoneme Set from which responses were drawn was alternated on consecutive trials. Other factors appeared in random order. The master list was divided into eight smaller lists. The first

108 trials became List 1, the second 108 trials became List 2, and so forth. A session consisted of the presentation of one of the lists to a subject.

The order in which lists were presented was counterbalanced across subjects. The list for the practice session was also used for the final session. Subjects saw the other lists only once.

There were three basic events on each trial: a response preparation period, a response period, and feedback. Subjects first saw a "Ready for next trial?" display, and pressed a "y" key to initiate the trial. They then saw the four CVCs for that trial displayed at the center of the screen, with the message "Prepare to say" displayed two lines above it. Eight seconds later, the "prepare to say" message was removed, and the subject heard three 417 Hz, 100 ms long warning tones at 400 ms intervals. The warning tones were followed by an 833 Hz, 100 ms long response signal. After this signal, a response latency was measured by a hardware voicekey, and the subject's response was tape-recorded. Eight seconds after the response signal, another 833 Hz, 100 ms long tone signalled the end of the response period and the display of the four CVCs was removed.

Subjects were instructed to use the eight seconds before the response signal to prepare the response, and to begin producing the sequence as soon as possible after they heard the signal. They were to repeat the sequence as many times as possible during the response period. Subjects were encouraged to speak as fast as possible without making errors, and to continue speaking through the end-of-trial signal.

Five hundred milliseconds after the trial-final signal, subjects saw a feedback display for 600 ms. The feedback showed whether the voicekey had registered a response and displayed the latency for the trial in centiseconds. The correct response was redisplayed, and an experimenter judged whether the response had been correct and intelligible. A code was entered to indicate a correct or an incorrect response. The subject then saw either a "Correct response" or an "Incorrect" message displayed for 600 ms, followed by a 500 ms delay, after which the "Ready for next trial?" query was redisplayed.

Trials were rejected if the response latency was less then 100 ms or longer than 800 ms, or if a mispronunciation, substitution, or other error occurred. Error trials were repeated once at the end of the session. There was a positive correlation between production time and the percentage of trials repeated by sequence condition ($r = .81$), so practice effects due to repeating trials would have tended to diminish rather than to inflate production time effects.

3. Results

Audiotapes were later replayed, and the number of CVCs produced on each trial was counted. All CVCs begun before the trial-final signal were included. Agreement between two raters was tested on 136 trials selected at random. Using one rater's counts to predict those of the other, a linear regression yielded an R^2 value of .984. The principal data were the production time means and the errors for each of the sequence conditions. Production time equaled the 8 s response period divided by the number of CVCs produced, and included both the latency and the duration of all of the CVCs produced on a trial.

3.1. *Overview of analyses*

Two analyses were performed. First, a standard ANOVA was used to test for differences among the sequence conditions and to determine whether these differences were independent of the Phoneme Set and Reversal factors. A regression analysis was then used to examine how the repetition pattern of each candidate unit contributed to a model of production time.

3.2. *Analysis of variance of production times*

Median production times by subject were collapsed across the Order factor and submitted to an analysis of variance. The five remaining variables, C_i pattern, V pattern, C_f pattern, Phoneme Set, and Reversal yielded a $3 \times 3 \times 3 \times 2 \times 2$ within-subjects design. Conservative Greenhouse–Geisser adjusted p-values are reported, along with standard degrees of freedom. No adjustments were made for experimentwise error, but the 27 main-effect and interaction tests should be taken into account when considering the possibility of Type I error.[4]

There were only small effects of Phoneme Set and Reversal on the factors of real interest, the C_i, V, and C_f repetition patterns. Production times were generally faster when the response was from the ptkn- rather than the dflr-set [261 ms per CVC vs. 277 ms; $F(1, 7) = 21.04$, $p < .005$], and there was a marginal interaction of the Phoneme Set factor with the Reversal factor [$F(1, 7) = 6.2$, $p < .05$]. There was also a three-way interaction of C_f pattern with Phoneme Set and Reversal [$F(2, 14) = 12.94$, $p < .005$]. This reflects a somewhat larger effect of the C_f pattern when /l/ or /r/ were the final consonants, but the order of the means was the same over all levels of the Phoneme Set and Reversal factors. The lack of crossover interactions of the Phoneme Set and Reversal factors with the repetition pattern of the C_i, V, or C_f allowed us to test hypotheses about the 27 sequence conditions without further concern for the particular sounds that were used.

Table 4 presents the means of the 27 conditions, and Table 5 shows the

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[4] Latencies for each trial were also submitted to an ANOVA design like that described for production time. The pattern of results for the latencies was consistent with that for production time, but effects were smaller. Production time did not appear to be a tradeoff between latencies and the number of syllables produced.

Table 4
Production time means and percentage of trials repeated, 27 sequence conditions

Repetition frequency
AAAA = 1 (Immediate repetition)
ABBA = 2 (Near repetition)
ABAB = 3 (Far repetition)
ABCD = 4 (Nonrepetition)

Repetition frequency, segments			Repetition frequency, larger units			Example	Production Time (ms)	Trials repeated due to errors (%)
Ci	V	Cf	CV	Rhyme	CVC			
1	1	1	1	1	1	pick pick pick pick	219	3
2	2	1	2	2	2	pick tuck tuck pick	226	6
2	2	2	2	2	2	pick ton ton pick	233	12
2	1	1	2	1	2	pick tick tick pick	234	7
2	1	2	2	2	2	pick tin tin pick	234	8
1	2	2	2	2	2	pick pun pun pick	236	7
1	2	1	2	2	2	pick puck puck pick	237	4
3	3	1	3	3	3	pick tuck pick tuck	248	13.5
1	3	1	3	3	3	pick puck pick puck	251	7
1	1	2	1	2	2	pick pin pin pick	254	4
3	1	1	3	1	3	pick tick pick tick	255	5
3	3	3	3	3	3	pick ton pick ton	259	11
3	1	3	3	3	3	pick tin pick tin	262	8
3	2	1	4	2	4	pick tuck puck tick	262	8
2	3	1	4	3	4	pick tuck tick puck	271	9
1	3	3	3	3	3	pick pun pick pun	273	10
1	1	3	1	3	3	pick pin pick pin	276	9
3	2	2	4	2	4	pick ton pun tick	286	14
3	2	3	4	4	4	pick ton puck tin	295	9
2	3	2	4	4	4	pick ton tin puck	295	13
3	1	2	3	2	4	pick tin pin tick	303	13
2	3	3	4	3	4	pick ton tick pun	304	15
3	3	2	3	4	4	pick ton pin tuck	304	15.5
1	3	2	3	4	4	pick pun pin puck	308	16
1	2	3	2	4	4	pick pun puck pin	314	14
2	2	3	2	4	4	pick ton tuck pin	316	18.5
2	1	3	2	3	4	pick tin tick pin	317	18

Table 5
Mean production time (ms) as a function of C_i, V, and C_f pattern

Repetition pattern	CVC slot		
	C_i	V	C_f
Identity	263	260	250
Near repetition	270	267	273
Far repetition	275	281	286

Note: Immediate repetition = AAAA; near repetition = ABBA; far repetition = ABAB.

main effect means of the three repetition patterns of the segmental components of the CVC. There were main effects of both V and C_f pattern ($F(2, 14) = 31.03$, $p = .0001$; and $F(2, 14) = 30.28$, $p = .0005$, respectively]. The Immediate repetition pattern was faster than the Near repetition pattern, which was faster than the Far repetition pattern, showing a *repetition benefit* for the V and C_f. There was no benefit for repeating the C_i, [$F(2, 14) = 4.04$, $p < .1$].

In addition to the main effects, each two-way interaction was significant [$C_i \times V$: $F(4, 28) = 15.85$, $p < .005$; $C_i \times C_f$: $F(4, 28) = 18.42$, $p < .005$; $V \times C_f$: $F(4, 28) = 22.96$, $p < .0005$]. These interactions are best understood by focussing on the effects of repeating suprasegmental units. Table 6 shows the production time means of the four repetition patterns for each suprasegmental unit, that is, the CVC, the rhyme, and the CV. In each case, immediate repetition yielded faster performance. This effect was largest for the CVC. Conclusions about the status of units should not be based on this analysis alone, though, because segments and suprasegmental units often have the same repetition patterns, so their repetition is often confounded.

3.3. *Regression models using repetition frequencies of units as predictors of production time*

An important feature of the design is that repetition effects for segments can be evaluated while holding the repetition pattern of larger units constant. Consider, for example, a comparison between the sequences *PICK TON TICK PUN* and *PICK TUCK TICK PUCK*. In both sequences, the CVC follows the ABCD pattern, while the rhyme and the vowel follow the ABAB pattern, but the C_f is repeated more often in the second sequence than in the first. This allows a test of the effect of repeating the C_f that is not confounded with effects of repeating the whole CVC or the rhyme. If the C_f is a parameter in the plan to produce the utterance, then by the editing view, the second sequence should be easier than the first.

Because of the weak interactions of the Phoneme Set and Reversal factors with the C_i, V, and C_f patterns, it was possible to collapse over Phoneme Set, Order, and Reversal, leaving just the means of the 27 sequence

Table 6
Mean production time as a function of monosyllable, rhyme and CV pattern

Unit	Repetition pattern			
	Immediate repetition AAAA	Near repetition ABBA	Far repetition ABAB	Non repetition ABCD
Syllable	219	236	261	298
Rhyme	236	252	273	305
CV	250	264	274	286

conditions to account for. The repetition patterns of candidate planning units were treated as equally spaced intervals of repetition frequency, and were given index values of one through four. These values represented increasing levels of difficulty under the editing hypothesis. The Immediate repetition or AAAA pattern was given a value of one because it should be the easiest. In the ABBA or Near repetition pattern, sounds in adjacent words are repeated half of the time, so it was given a value of two. The Far repetition pattern, which did not repeat sounds in adjacent CVCs, was given a value of three. Finally, the ABCD or Nonrepetition pattern was given a value of four, because there was a greater delay in repeating sounds in this pattern than in the other patterns. This representation is justified on two grounds. First, the patterns indexed as one, two, and three represent equal interval proportions of repetition frequency. In addition, mean production times for segments and suprasegmentals increased more or less linearly for the four patterns, as shown in Tables 5 and 6. The regression analysis uses indices that represent the repetition frequency of suprasegmental units directly, rather than as interaction terms. The predictors are called *Repetition Frequency* factors, abbreviated as C_i *RF*, *V RF*, C_f *RF*, *CV RF*, *Rhyme RF*, and *CVC RF*, respectively. Index values for each factor and each sequence condition are given in Table 4. These factors will be used to predict the 27 production-time means. An index with a positive slope shows a repetition benefit. An index with a negative slope shows a repetition cost, and would be consistent with the phonological competition account.

3.4. Regression results

The best single predictor of production time was CVC repetition. A model using only this index accounted for 80% of the variance among the 27 means [Production Time = 179 + 25.8 (CVC RF)]. The positive slope shows that this effect is a benefit. Some smaller units also showed a repetition benefit, but only two predictors significantly improved R^2 at a criterion of $p < .05$. These were the Rhyme RF and C_f RF predictors, which accounted for 54% and 38% of the variance, respectively, when used in single-predictor models.

Clearly the fastest performance was for sequences that repeated whole CVCs. This finding is consistent with both the editing view and the phonological competition model. In the latter, repeating the largest unit should be beneficial because of lingering activation from a prior episode. The monosyllable thus meets the definition of a planning unit under either theory.

The remainder of the models that will be reported are the result of an all-possible-subsets regression. Adjusted R^2 and Mallow's C_p statistic were used to assess whether a predictor improved the prediction sufficiently to justify adding it to the model. These models always retained CVC RF as one of the factors, and added other predictors to it. This amounted to a search

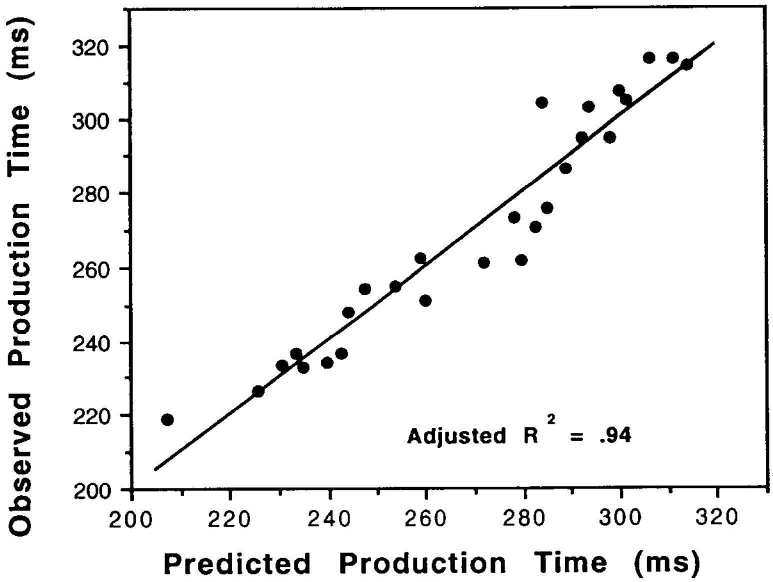

Fig. 3. Predicted versus observed production time for the best multiple regression model, using 4 repetition frequency predictors. Production time = 177.43 + 35.13 (CVC RF) − 9.55 (CV RF) + 7.43 (C_f RF) − 3.4 (C_i RF).

for variables that were important when whole CVCs were *not* repeated in the sequence. The best models showed a benefit for repeating the C_f, but showed strong inhibitory effects for repeating the C_i and the CV. That is, once the effect of repeating whole CVCs was factored out, repeating onsets or CVs *slowed* production. These inhibitory effects suggest that there are competition processes that come into play when some but not all parts of the CVC are repeated.

The best model by both the R^2 and C_p criteria used four predictors. CVC and C_f repetition had facilitative effects, but the effects of C_i and CV repetition were inhibitory.[5] Figure 3 shows predicted and obtained values of production time for this model with four factors, together with the model slopes and intercept.

4. Discussion

One of the striking findings of this experiment was that, although there was strong evidence for the use of CVC monosyllables as planning units, there was no clear evidence for the use of either the rhyme or the CV. There

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[5] A model that included the vowel with the monosyllable, C_i, and C_f showed that the vowel is also weakly inhibitory [Production Time = 179.8 + 31.07 (CVC RF) − 7.96(C_i RF − 4.85(V RF) + 9.23 (C_f RF)]. The t-to-enter values for these factors are 11.77, −3.25, −1.98, and 3.76, respectively. All except the vowel make significant contributions to the model at $p < 0.05$.

was a facilitative trend for rhyme repetition, but this was almost entirely due to repeating the C_f. Similarly, the inhibitory effect of repeating the CV was largely due to the onset. The general pattern of effects was one of facilitation for repeating the CVC and inhibition for repeating some of the smaller units, providing support for a phonological competition view over an editing view of the data.

A second unanticipated effect was that the direction of the effect of repeating subsyllabic units depended on the *location* of that unit in the CVC. Initial consonants and CVs had negative slopes, indicating that repeating these units had an inhibitory effect on rate of speech. Final consonants showed a repetition benefit. Because the phonological competition model assumes that all of the segments of a CVC are activated simultaneously, the model does not predict location-based differences in the direction of the effects.

To further examine these locational effects, we turned to tests of pairwise contrasts (see Table 7). These contrasts tested the effect of C_i and C_f repetition by comparing pairs of conditions in which the repetition frequency of the C_i or C_f differed, but the repetition frequency of all other units (i.e., the remaining segments, the CVC and the rhyme) was held constant. Although there are not enough observations in any one condition for the contrasts to be reliable in every case, we can look at the overall pattern of results. Of the ten such contrasts for the C_i, nine were inhibitory. The one in the wrong direction differed by only 2 ms. Of the 6 contrasts for the C_f, 5 are facilitative and the other is contrary by 1 ms. The table shows F-values for each contrast. Overall, there was a pattern of facilitation for repeating the C_f and inhibition for repeating the C_i.

A second test compared conditions that repeated the C_i or the C_f to a baseline condition in which *no* segments were repeated across two distinct CVCs in the sequence. Four of the tabled contrasts (contrasts 2, 4, 12, and 14) are relevant. Each of these sequences had two distinct CVCs that followed either the Near repetition or the Far repetition pattern. In each contrast, one condition repeated either only a C_i or a only a C_f across the two distinct CVCs, and the remaining segments and suprasegmentals were held constant. The conditions used as a baseline did not repeat any phonemes in the two CVCs. To test the hypothesis that C_i repetition was inhibitory, we compared the mean of the INN and IFF conditions (repeating the C_i) to the mean of NNN and FFF conditions (with no shared segments) and found significant inhibition relative to this baseline [$F(1,7) = 12.92$, $p < .01$]. A corresponding test showing a benefit of C_f repetition was also reliable [(NNI + FFI vs. NNN + FFF); $F(1,7) = 19.35$, $p < .005$].

Our finding that performance was slowed by repeating initial sounds and speeded by repeating final sounds of CVC words was unanticipated. The only previous report of such an asymmetry, to our knowledge, was Butterworth and Whittaker (1980), who examined the likelihood of errors in the repeated production of pairs of CVCs. When subjects produced CVC pairs like *bat gat*, they completed an average of 6.4 sequences before making

Table 7
Effects of C_i repetition, holding the repetition pattern of other segments and suprasegmentals constant

Rhyme and monosyllable pattern = ABBA	
(1) IIN vs. NIN = 254 vs. 234	$F(1,7) = 23.04$ $p < .005$
(2) INN vs. NNN = 236 vs. 233	$F(1,7) = .78$ $p < .5$
(3) INI vs. NNI = 237 vs. 226	$F(1,7) = 8.23$ $p < .05$
Rhyme and monosyllable pattern = ABAB	
(4) IIF vs. FIF = 276 vs. 261.5	$F(1,7) = 15.66$ $p < .01$
(5) IFF vs. FFF = 273 vs. 259	$F(1,7) = 23.0$ $p < .005$
(6) IFI vs. FFI = 251 vs. 248	$F(1,7) = .58$ $p < .5$
Rhyme and monosyllable pattern = ABCD	
(7) INF vs. NNF = 314 vs. 316	$F(1,7) = .22$ $p < 1.0$
(8) INF vs. FNF = 314 vs. 295	$F(1,7) = 15.46$ $p < .01$
(9) IFN vs. NFN = 307.5 vs. 295	$F(1,7) = 14.92$ $p < .01$
(10) IFN vs. FFN = 307.5 vs. 304	$F(1,7) = .67$ $p < .5$

Effects of C_f repetition, holding the repetition pattern of other segments and suprasegments constant

Rhyme and monosyllable pattern = ABBA	
(11) INI vs. INN = 237 vs. 236	$F(1,7) = 00.0$ $p < 1.0$
(12) NNI vs. NNN = 226 vs. 233	$F(1,7) = 2.02$ $p < .5$
Rhyme and monosyllable pattern = ABAB	
(13) IFI vs. IFF = 251 vs. 273	$F(1,7) = 20.85$ $p < .005$
(14) FFI vs. FFF = 248 vs. 259	$F(1,7) = 11.25$ $p < .05$
Rhyme = ABBA, monosyllable = ABCD	
(15) FNI vs. FNN = 262 vs. 286	$F(1,7) = 7.01$ $p < .05$
(16) NFI vs. NFF = 271 vs. 304	$F(1,7) = 14.27$ $p < .01$

an error. In another experiment, subjects producing sequences like *tab tag* made errors after only 3.2 sequences, on average. Butterworth and Whittaker suggested that this asymmetry arose because the initial consonants were part of the address used in accessing words for production. Most models of speech production (e.g., Dell, 1986; Shaffer, 1976; Shattuck-Hufnagel, 1979) have assumed that there is some kind of pointer to the word currently being encoded. The word might be specified by giving a position in a buffer or by indexing its content. Butterworth and Whittaker suggested that sequences like *tab tag* are difficult because the specification for both words included *#t__*. Since initial consonants are part of the address, words that share initial consonants are apt to be confused. If we assume that this mechanism affects production time as well as errors, the cost of repeating onsets can be explained.

The phonological competition model's account of why shared initial sounds make a sequence difficult is similar in spirit. When the intended word becomes activated, the activated phonemes feed back onto all other CVCs that incorporate the same sounds. This is a form of content addressing. When the intended phonemes become activated, they bias the system to activate words that share these sounds, causing trouble when nearby words share sounds.

The phonological competition model retrieves all segments concurrently, and cannot account for the different effects of repeating initial and final sounds. The solution is to change this assumption. Meyer (1991) and Houghton (1990) have proposed that phonemes are activated sequentially. By adding this idea to the phonological competition model, we can account for the location-based effects. The revised model is depicted in Figs. 4 and 5.

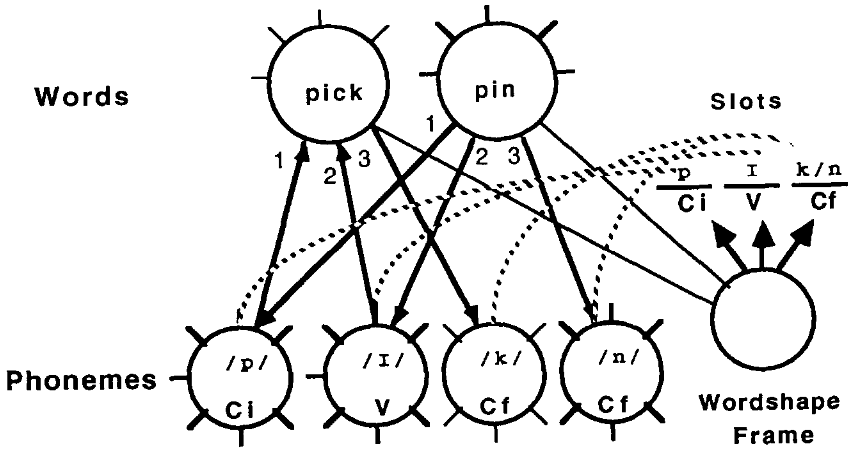

Fig. 4. Sequential cuing model. The effect of having just produced *PICK* on the production of *PIN*.

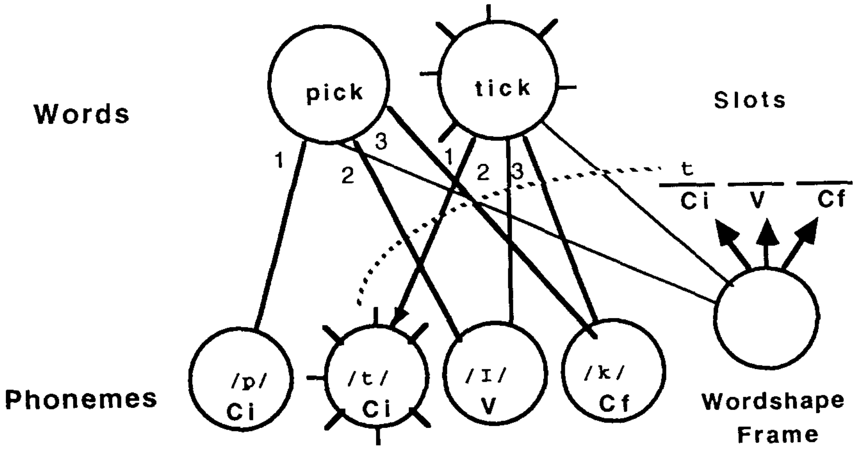

Fig. 5. Sequential cuing model. The effect of having just produced *PICK* on the production of *TICK*.

In the new model, the basis for initial inhibition and final facilitation is a phenomenon we will call *sequential cuing*. If activation initially spreads to the onset, then to the vowel and then the final consonant, shared sounds produce competition between sounds that *follow* the repeated ones. When the C_i or CV of adjacent words match, the activation of the initial sounds of the intended word will feed back to the node for the similar word. The result is miscuing of the C_f. The C_f for the competing word receives extra activation, with the result that encoding of the correct C_f is delayed. On the other hand, if final sounds are shared, there is no miscuing. This is because by the time activation is sent to the nodes for these sounds, nothing else in the word remains to be miscued. Instead, repeated final sounds are selected faster, due to the reactivation of nodes. The following error analysis for Experiment 1 and two new experiments are offered as tests of the sequential cuing hypothesis.

4.1. Error analysis

According to the phonological competition model, production times are slowed due to competition between discrepant sounds in identical positions of nearby words, and competition increases when words share more than one sound. The new model, called the *sequential cuing model*, asserts that similarity-based competition operates from left to right, and that shared segments can miscue the production of later sounds. If this is true, errors in which one sound is replaced by another from a nearby word should be triggered by repeated sounds that *precede* the error within the word, more often than by repeated sounds that *follow* the error.

All errors in sessions two and seven for all subjects were examined by listening to the error trials. The first error in the production of a sequence was used in the subsequent analysis. There were 132 errors in the 1728 trials in the sample. The errors that were clear tests of the sequential cuing hypothesis were replacements of one consonant by another consonant, where the erroneous consonant comes from an identical slot in a nearby CVC. There were 33 initial- and 74 final-consonant substitutions in this sample.

Each error was categorized as to whether it could have been cued by another CVC in the sequence that shared sounds with the correct CVC. When there was more than one potential source of error, the CVC sharing the greatest number of sounds with the target CVC was deemed the source. For example, saying "laid reef raid reef" for "laid reef raid leaf" was coded as /r/ replacing /l/ in "leaf" because of the influence of the shared /if/ from "reef". Such errors were therefore assumed to be cued by the shared VC, and to be *right* cued, because the repeated material *followed* the location of the error in the CVC. Similarly, the final consonant error "fair feel feel fail" (for "fair feel fear fail") was assumed to be *CV-* and *left* cued. VC-cued errors were C_i substitutions. CV-cued errors involved final consonants. Other right-cued errors included C_i errors cued only by the C_f or only by the V. Other left-cued errors included C_f errors cued only by the C_i or only by the V. Finally, it was possible for initial or final consonant errors to be uncued.

The sequential cuing hypothesis predicts that right cuing should be less likely than left cuing. The inventory of errors in Table 8 supports this prediction. Final consonant errors cued by shared CVs were more common than initial consonant errors cued by shared VCs (41 to 22), and errors that were left-cued by a single sound were more frequent than errors that were right-cued by a single sound (30 to 8). Finally, uncued initial and final errors were infrequent and equally likely (3 to 3). Because of the symmetrical design of the materials, differences between right and left cuing cannot be attributed to factors other than the immediate sequence in which the sounds become active.

The errors and production times from Experiment 1 supported the sequential cuing hypothesis. Experiment 2 was an attempt to replicate four of the conditions of Experiment 1 and to obtain more data on the locational effects. Four sequence conditions that corresponded to the previous IIF, FII, IFF, and FFI conditions were tested, this time using pairs of CVC words. These sequence conditions are illustrated in Table 9. The sequential cuing hypothesis predicts that initial repetition should be more difficult than final repetition (e.g., CAT CAB > CAT BAT and CAT CUB > CAT BUT) and that this difference should be greater when two sounds are shared rather than one (e.g., CAT CAB – CAT BAT > CAT CUB – CAT BUT). The second prediction arises from the fact that two shared sounds allow more activation to spread from the target to the competing CVC, leading to increased activation of any discrepant sounds that follow them. This

Table 8
Types of production errors, Experiment 1 (sessions 2 and 7)

A. Frequency of error types

Type of error	N
Substitutions (movement errors within the sequence)	123
Pauses (No overt error)	4
Featural errors not resulting in another correct phoneme in the sequence	2
Cluster error (consonant cluster produced instead of single final consonant)	1
Phoneme intrusion (substitution of a sound not belonging to the sequence)	1
Stutter (very rapid repetition of prior CVC)	1
Total	132

B. Frequency of substitution errors

Type of error	
Substitutions of 2 segments	6
Initial consonant substitutions	33
Vowel substitution	10
Final consonant substitutions	74
Total	123

C. Frequency of cued errors, initial and final consonants

1. Initial consonant substitution errors

Type of error	Correct sequence (cue is underlined)	Actual sequence (error is underlined)	N
VC-cued	laid reef raid leaf	laid reef raid reef	22
C_f-cued	pun tin tin pun	pun tin pin. . .	5
V-cued	pick ton tin puck	tick. . .	3
Uncued	knit cup cup knit	kit	3
Total			33

2. Final consonant substitution errors

Type of error	Correct sequence (cue is underlined)	Actual sequence (error is underlined)	N
CV-cued	fair feel fail fear	fair feel fair	41
C_i-cued	nut kip cut nip	nut kit. . . cut nip	10
V-cued	fail deer dare feel	fail deal dare feel	20
Uncued	fail deer fail deer	fail deer fail deal	3
Total			74

prediction can be contrasted with the view that stored words are addressed only by their initial sounds (Butterworth & Whittaker, 1980). If this is the case, then the difference in production times for CAT CAB and CAT BAT should be equal to the difference between CAT CUB and CAT BUT.

EXPERIMENT 2

5. Method

5.1. Subjects

Twelve new subjects were recruited from an undergraduate subject pool at the University of Illinois. Participation in the subject pool was part of a course requirement. Each subject took part in one session lasting about one hour, and each completed one replication of the design.

5.2. Materials

A new set of materials was designed, consisting of pairs of CVCs. The four sequence conditions used are shown in Table 9. Pairs of CVCs differed by at least one and at most two phonemes. A pair of words could either share only an initial consonant or only a final consonant, or could share only a CV or only a rhyme. The four conditions were represented as two levels of two factors. *Location* referred to the position of the repeated sound in the CVC: either initial or final position. *Size of Overlap* referred to the number of segments repeated in the CVC–CVC sequence (i.e., either one or two contiguous segments).

As before, the sequence conditions were crossed with different phoneme sets and different orderings of phonemes, so that effects of the sequence conditions could be isolated from effects of particular phonemes. This time the phoneme sets were made up of two sets of consonants and two sets of

Table 9
Sequence conditions, Experiment 2

Sequence condition	Example	Location	Size
C_iV repetition	CAT CAB	1	1
C_i repetition	CAT CUB	1	2
VC_f repetition	CAT BAT	2	1
C_f repetition	CAT BUT	2	2

Key to variable codes:
Location 1 = syllable-initial sound(s) repeated
2 = syllable-final sound(s) repeated
Size of overlap 1 = one phoneme repeated
2 = two phonemes repeated

Table 10
List of CVC words and pronounceable nonwords in Experiment 2

/kls/set	/drl/set
KEEL, SEAL, KALE, SAIL	DEER, LEER, DARE, LAIR
KEES, LEASE, CASE, LACE	DEAL, REAL, DALE, RAIL
LEEK, SEEK, LAKE, SAKE	LEAD, READ, LAID, RAID

/ktb/set	/npt/set
CAT, BAT, CUT, BUT	GNAT, PAT, NUT, PUTT
CAB, TAB, CUB, TUB	NAP, TAP, NUP, TUP
TACK, BACK, TUCK, BUCK	TAN, PAN, TON, PUN

vowels. Consonant sets were nested within vowel sets. Vowel Set 1 was crossed with Consonant Sets 1 and 2, and Vowel Set 2 was crossed with Consonant Sets 3 and 4, yielding four different *Phoneme Sets*. The CVC words and pronounceable nonwords used in the design are listed in Table 10. As before, the order in which the particular consonants or vowels in each set appear in the sequence was permuted. There were six possible levels of *Consonant Order* and two levels of *Vowel Order*. Except for Vowel Set, all factors were fully crossed, resulting in a 2 (Size) × 2 (Location) × 6 (Consonant Order) × 2 (Vowel Order) × 4 (Phoneme Set) design, or 192 distinct response sequences.

5.3. Design and procedure

Each subject was given instructions and completed 16 practice trials before being presented with the 192 test trials in random order. The procedure was identical to that of Experiment 1 except for two details. The preparation and response periods were each shortened to four seconds because there were only 2 CVCs in a sequence, and the display of the response sequence was removed from the screen prior to the onset of the warning signals and response signal.

6. Results and discussion

Production times were collapsed over the Order factors, and were submitted to a 2 (Location) × 2 (Size of Overlap) × 4 (Phoneme Set) repeated measures analysis of variance. Table 11 shows the principal results.

An ANOVA on production-time means showed main effects of both Location and Size of Overlap. Subjects were slower when initial rather than final segments were repeated [271 ms per CVC vs. 295 ms; $F(1, 11) = 74.66$, $p < .0001$). Subjects were also slower, overall, when more segments were repeated, suggesting that for this set of materials, inhibitory processes

Table 11
Production time (and percent repeated trials) for sequence conditions, Experiment 2

Location	Size	
	One phoneme	Two phonemes
Initial	288 (5%)	302 (5%)
Final	271 ((6.5%)	269 (4.5%)

Note: Numbers in parentheses indicate the percentage of trials repeated due to errors in the production of a sequence, by condition.

outweighed facilitative processes [280 vs. 286 ms; $F(1, 11) = 15.2$, $p < .005$]. Marginals for the Phoneme Sets were 279, 287, 291, and 274 ms, respectively, for the kls-, drl-, ktb-, and ntp-sets [$F(3, 9) = 11.34$, $p < .005$].

There was an interaction of Size of Overlap with Location. The locational asymmetry was greater when two segments were repeated than when one was [$F(1, 11) = 46.53$, $p < .0001$]. There was also an interaction of the Phoneme Set factor with the Location factor [$F(3, 9) = 9.8$, $p < .005$], but the difference between Phoneme Sets was one of effect size and not a crossover interaction, as shown in Figs. 6 and 7. These figures also illustrate the increase in effect size with increased Size of Overlap.

The results supported the predictions of the sequential cuing model. Repeating sounds at the beginning of the CVC led to longer production times than did repeating them at the end. In addition, the size of these effects depended on the degree of overlap between the two words.

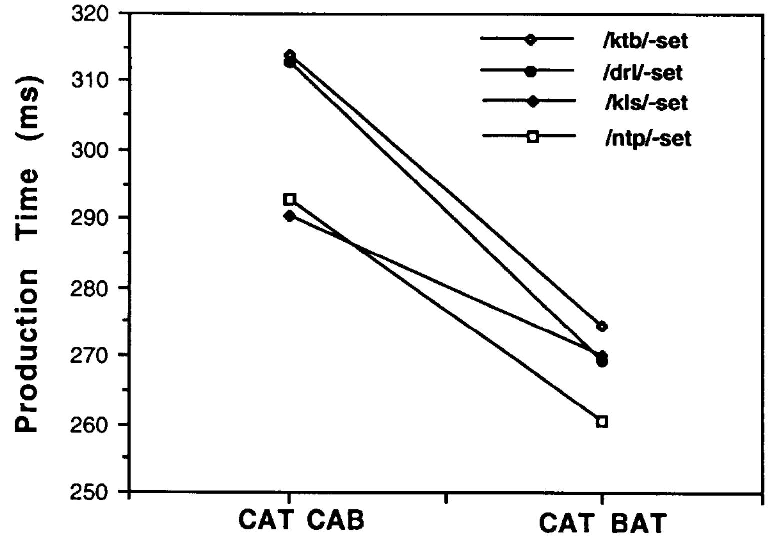

Fig. 6. Production time by location of repeated units and phoneme set for sequences with two repeated phonemes.

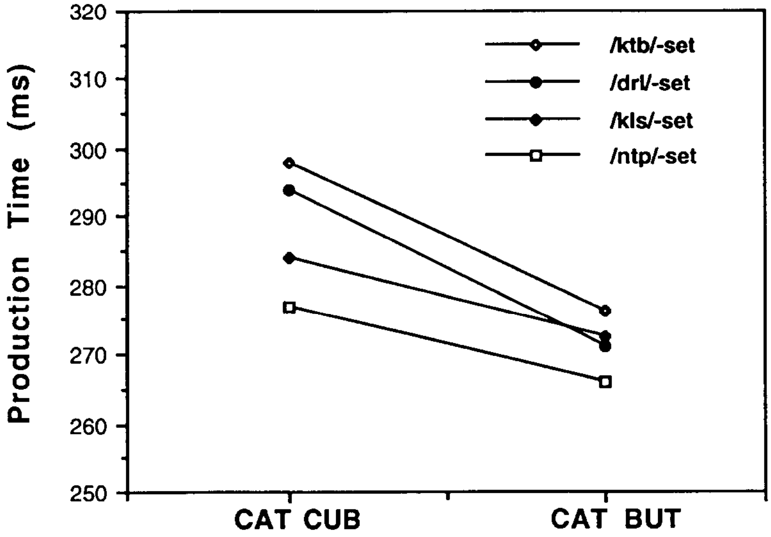

Fig. 7. Production time by location of repeated units and phoneme set for sequences with a single repeated phoneme.

Inhibition was greater when two segments were repeated rather than one, suggesting that miscuing was not controlled only by shared initial sounds.

EXPERIMENT 3

Our studies were initially motivated by two approaches to phonological encoding, an editing or parameter remapping view and the phonological competition model. The finding that the effects of repetition were sometimes inhibitory was inconsistent with the editing view, and the finding that effects were location-based was unexplained by the phonological competition model. To account for these effects, a new model, the sequential cuing model, was proposed. This model simply adds the assumption of sequential activation to the phonological competition model.

A question that remains unanswered, however, is the domain within which sequential cuing operates. As we have described the sequential cuing model, competition is due to the flow of activation from sound nodes to higher-level nodes. Up to this point we have been unable to say with certainty what these higher-level units are, i.e., syllables or words. Following Peterson et al. (1989), we have assumed that they are words, but the previous studies could not tell us whether words or syllables mediated the effects. Since these studies showed sequential cuing to be a reliable effect, perhaps the effect can help us to determine whether words or syllables act as higher-level planning units. If the higher-level unit is the word (or something larger than syllables), then cuing should extend across syllable boundaries within the same word. To test this we need to look at the production of multisyllabic words.

Experiment 3 used pairs of CVCVC bisyllabic words like CATTLE BUTTER. The goal was to determine whether shared sounds in the first syllable of the word would cue the selection of sounds in the second syllable of that word. The bisyllables were expansions of the CVC structures used in the previous two experiments. Where Experiments 1 and 2 used C_iVC_f words, Experiment 3 moved the C_f into another syllable by inserting some extra sounds between the first-syllable V and the C_f. The stimuli were thus $C_iV_1CVC_f$ words. The medial C and V were always repeated. We manipulated whether the C_i, the V_1, or the C_f were repeated in the pair or not. The eight sequence conditions that result are shown in Table 12. These conditions were analogous to the III, IIF, IFI, IFF, FII, FIF, FFI, and FFF conditions of Experiment 1. Four of these conditions were also used in Experiment 2, namely, the IIF, FII, IFF, and FFI conditions. A bisyllable sequence like CATTLE BATTLE is analogous to the CAT BAT condition of Experiment 2, for example, in that the V_i and C_f are repeated, but the C_i is not. Similarly, CATTLE CUTTER repeats the C_i but alternates the V_i and C_f like the CAT CUB condition of Experiment 2. If placing the C_f in a different syllable does not eliminate the sequential cuing effect, we expect inhibition when the C_i was repeated compared to when it was not, and facilitation for repeating the C_f. In addition, we expect to find the condition in which the C_i and V_i were repeated but the C_f was not (e.g., CATTLE CATTER) to be especially difficult. If, on the other hand, miscuing effects are confined to the syllable, then this condition should be easy. There are no discrepant sounds in the syllable with the repeated C_iV_1, so no miscuing should occur.

Table 12
Sequence conditions for the bisyllabic word pairs of Experiment 3

	Sequence condition										Example
(1)	C_i1	V1	C	V	C_f1	C_i1	V1	C	V	C_f1	CATTLE CATTLE
(2)	C_i1	V1	C	V	C_f1	C_i1	V1	C	V	C_f2	CATTLE CATTER
(3)	C_i1	V1	C	V	C_f1	C_i1	V2	C	V	C_f1	CATTLE CUTTLE
(4)	C_i1	V1	C	V	C_f1	C_i1	V2	C	V	C_f2	CATTLE CUTTER
(5)	C_i1	V1	C	V	C_f1	C_i2	V1	C	V	C_f1	CATTLE BATTLE
(6)	C_i1	V1	C	V	C_f1	C_i2	V1	C	V	C_f2	CATTLE BATTER
(7)	C_i1	V1	C	V	C_f1	C_i2	V2	C	V	C_f1	CATTLE BUTTLE
(8)	C_i1	V1	C	V	C_f1	C_i2	V2	C	V	C_f2	CATTLE BUTTER

Note: VC_f corresponds to syllabic /l/ or /r/ in some cases.

7. Method

7.1. *Subjects*

Eight new subjects took part in the study. Each completed the full design.

7.2. *Materials and design*

Materials consisted of pairs of bisyllabic $C_iV_iCVC_f$ words. There were eight sequence conditions. The medial C and the following V were always repeated.[6] Pairs of bisyllables could either share or not share the same C_i, the same V_i, or the same C_f. All possible combinations of either repeating or not repeating the C_i, V_i, and C_f sounds appeared in the design, creating $2 \times 2 \times 2 = 8$ sequence conditions.

Again, to expand the number of sequences, two nonstructural factors were included in the design. There were two Phoneme Sets. The first had /b/ and /k/ as possible initial consonants and /ae/ and /ʌ/ as possible first-syllable vowels. The medial consonant was always /t/. The final (second-syllable) consonants were /l/ and /r/. The second Phoneme Set had /p/ and /w/ as initial consonants and /I/ and /ae/ as first-syllable vowels. The medial consonant was always /k/. The possible final consonants were /t/ and /r/, yielding sequences like PICKER WICKET. Table 13 shows the sixteen bisyllables that were used.

Sounds could be assigned to slots in one of two *Orders*. The order of C_i phonemes could be /b/, /k/ versus /k/, /b/, or /p/, /w/ versus /w/, /p/. The order of V_i values could be /ae/, /ʌ/ or /ʌ/, /ae/, for instance. Finally, C_f values could be ordered /l/, /r/ or /r/, /l/, for example. The Order factor contributed eight levels to the design, and was crossed with the other factors. The full design was an 8 (Sequence Conditions) × 2 (Phoneme Sets) × 8 (Order) factorial design, yielding 128 distinct response sequences.

Table 13
Bisyllabic words and pronounceable nonwords used in the materials

Phoneme set 1
CATTLE, CUTTLE, BATTLE, BUTTLE
CATTER, CUTTER, BATTER, BUTTER

Phoneme set 2
PICKET, PACKET, WICKET, WACKET
PICKER, PACKER, WICKER, WHACKER

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[6] In many phonological analyses, the final VC_f in words like CATTLE and BATTER is analyzed as a single syllabic consonant, rather than a VC_f sequence. For this reason one might not want to view bisyllables with final /l/ or /r/ in our materials as CVCVCs. This distinction has no impact on our predictions for the study, however, as the sounds are word-final regardless of the analysis.

Unlike the previous experiments, there was no factor that reversed the assignment of sounds to the initial vs. final position. Since initial and final consonant sets had different sounds, it was all the more important to establish that the effects of sequence conditions were more or less the same across phoneme sets.

7.3. Procedure

The procedure was identical to that of Experiment 2. All subjects completed the full design. Production time per syllable was the principal dependent measure.

8. Results

To evaluate Phoneme Set effects, production time means were submitted to a within-subjects analysis of variance collapsing over the Order factors. The factors included in the analysis were thus C_i Repetition (vs. Nonrepetition), V_i Repetition, C_f Repetition, and Phoneme Set.[7]

Production time means for each Sequence Condition are shown in Table 14. There were main effects of both C_i Repetition and C_f Repetition [$F(1,7) = 18.55$, $p < .005$ and $F(1,7) = 54.7$, $p < .0005$, respectively]. As in the previous experiments, the direction of these effects depended on the location of the repeated sounds. Repeating the C_i slowed subjects' production time (192 ms per syllable vs. 187 ms; repetition vs. nonrepetition), but repeating the C_f was beneficial (179 vs. 201 ms; repetition vs. nonrepetition). There were no main effects of V_i repetition or of Phoneme Set. The percentage of trials repeated due to error closely followed the production time results (see Table 14).

There was an interaction of V_i Repetition by C_f Repetition. The cost of not repeating the C_f was greater when the vowel of the initial syllable was repeated (25 ms) than when it was not (18 ms); [$F(1,7) = 10.79$, $p < .05$]. In addition, there was a three-way interaction of C_i Repetition, V_i Repetition, and C_f Repetition [$F(1,7) = 8.33$, $p < .05$]. Again, the cost of not repeating the C_f was largest when both the C_i and V_i were repeated. Since these

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[7] The structure of CVCVC bisyllables in English is generally agreed to be ambisyllabic. That is, the medial consonant participates in both the initial and final syllables. This is especially likely for CVCVCs with initial-syllable stress, as in the words used here. For a review of the behavioral evidence for ambisyllabicity, see Treiman and Danis (1988). For current purposes, we assume that the intervocalic consonant is both in the coda of the initial syllable and in the onset of the final syllable. Since the point is to examine whether cuing can occur across more than the syllable, and since repetition conditions are used that involve repeating units that are wholly in the first syllable or wholly in the second syllable, the exact location of the syllable boundary is not of concern. We have not tried to decompose these effects into exact contributions of initial versus final syllable repetition, however, for this reason.

Table 14
Production time means by sequence condition, collapsing over phoneme set and order factors (ordered by production time)

Example	Word	C_i	V	CV	C_f	Production time	Trials repeated (%)
CATTLE BATTLE	2	2	1	2	1	175	7
CATTLE BUTTLE	2	2	2	2	1	176	6
CATTLE CATTLE	1	1	1	1	1	178	5
CATTLE CUTTLE	2	1	2	2	1	184	10
CATTLE BUTTER	2	2	2	2	1	197	16
CATTLE BATTER	2	2	1	2	2	197	20
CATTLE CUTTER	2	1	2	2	2	199	20
CATTLE CATTER	2	1	1	1	2	204	24

Key to repetition indices: 1 = Repetition; 2 = Nonrepetition.

interactions imply an effect of sounds in the first syllable on sounds in the second syllable of the same word, they provide specific evidence that sounds for the entire word are activated in sequence. The most difficult condition had repeated sounds in the first but not the second syllable. If miscuing was confined to the syllable, this condition would be easy because the first syllables of the two words contain no discrepant sounds (e.g., CATTLE CATTER). Finally, there was a nominal 3-way interaction of V_i Repetition by C_f Repetition by Phoneme Set [$F(1, 7) = 6.35$, $p < .05$], but again this was not a crossover interaction. The effect of V_i and C_f Repetition was largest in the bklr-set, but the same pattern of effects was seen in both Phoneme Sets.

The remainder of the analysis involved finding the best multiple regression model of production time for this experiment. The data were collapsed over all of the nonstructural factors and over subjects, leaving the eight means for the sequence conditions to be fitted. Five predictor variables were used. These predictors were indices of Whole Word Repetition, C_i Repetition, V_i Repetition, C_iV_i Repetition, and C_f Repetition, which in these materials is the same as repeating the whole final syllable. Each predictor had two levels, a repetition and a nonrepetition level. An all-possible-subsets regression was used to find the best model of production time among these predictors.

The best model, overall, had two predictors (Adjusted $R^2 = .95$, $C_p = 2.24$). C_f Repetition was facilitative and C_i Repetition was inhibitory. The prediction equation for production time in this model was $164.7 + 20.94$ (C_f Repetition) $- 4.98$ (C_i Repetition). The C_f Repetition factor accounted for 90% of the variance among the eight means, and adding the C_i-Repetition factor to the model brought the percentage of variance accounted for up to 95% (t-to-enter $= -2.7$, $p < .05$). As in Experiments 1 and 2, repeating initial material slowed subjects' production, but repeating final material was beneficial.

9. Discussion

As in the previous two experiments, there were locational asymmetries that suggested left-to-right activation, but because the materials of Experiment 3 were bisyllables, the results provide evidence about what higher-level units are represented. Unlike the previous experiments, cuing could and did occur across syllable boundaries within a word, leading us to conclude that units higher than the syllable mediate these effects. These higher-level units may be words.

Only one aspect of the results was inconsistent with the previous studies: the finding that repetition of the whole word was not the fastest condition. Sequences in the word-repetition condition (CATTLE CATTLE) were produced about as quickly as sequences like CATTLE BATTLE or CATTLE BUTTLE. In fact, the lack of a bisyllable effect in Experiment may be because performance is at floor. If this experiment had included a wider range of conditions for comparison, including conditions involving sequences of four different words (as in Experiment 1), a benefit of repeating the bisyllable over repeating final consonants might have been shown.

GENERAL DISCUSSION

The sequential cuing model accounts for the basic findings of all three experiments. Experiment 1 demonstrated that CVC words act as planning units by showing that 80% of the variance in production time is accounted for by an index of CVC repetition, showing a repetition benefit. The model accounts for this effect by using nodes that are more easily activated when they have recently been used.[8] The first experiment also showed that after partialling out the effect of repeating the CVC, only C_f repetition was beneficial. Repeating units at the beginning of the CVC slowed production and encouraged substitution errors in later positions in the word. These findings were replicated in Experiments 2 and 3, with Experiment 3 extending them to multisyllabic words. In short, it was easier to produce a sequence like PICK TICK than one like PICK PIN.

The sequential cuing model accounts for the beneficial effect of repeating final sounds in the same way it accounts for the effect of repeating whole CVC words. Recent use makes a unit more accessible. Repeating non-final units is detrimental because it creates competition between discrepant units that follow the repeated ones. The difference between initial and final

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[8] The implemented model of Peterson et al. (1989) actually has two mechanisms for facilitation, one based on residual activation and one based on newly created episodic nodes, but our studies do not address the distinction between these mechanisms.

repetition is illustrated in Figs. 4 and 5. When the C_i and V of adjacent CVCs match, as in Fig. 4, the activated C_i and V of the target word activate the competing word and thereby its final consonant. Miscuing doesn't occur when only final consonants are repeated, though, because of the sequential encoding assumption. If final sounds are the last to be encoded, they cannot trigger competition for the assignment of other sounds.

The sequential cuing model may help to clear up some conflicting results in the literature on form-related priming. Lupker and Colombo (1990) found facilitative effects of rhyme primes in a naming task, but Peterson et al. (1989) and Bock (1987) found inhibition for primes with shared initial CVs. The difference in the direction of these effects can be entirely attributed to the location of the shared material in primes and targets. The sequential cuing model provides a unified account for why priming effects were inhibitory in some cases and facilitative in others.

The model makes claims about what the planning units in speech production are. Specifically, it claims that nodes in the network are the major planning units. To account for our data, the model needs nodes for words and nodes for phonemes. We would also not want to rule out the use of syllable nodes, but there is nothing in the data that compels their use. The model's sequential assumption allow it to account for differences in the effect of repeating phonemes in different locations of syllables and words. A complete model would also have feature nodes connecting to the segments. It is well known that sequences of phonemes with shared features are hard to produce, compared to sequences with dissimilar phonemes (e.g., Butterworth & Whittaker, 1980; Kupin, 1979; MacKay, 1970; Meyer & Gordon, 1985; Yaniv, Meyer, Gordon, Huff, & Sevald, 1990), an effect replicated in the error data from Experiment 1. Most of the consonant substitutions involved similar phonemes (e.g., /r/ for /l/, /p/ for /t/, but not /f/ for /d/ or /k/ for /n/). Spreading-activation models that use feature nodes have shown that encoding a sound is more difficult in the context of a similar sound (Dell, 1986). Since features are activated via phoneme nodes, the same kind of competition that occurs between words that share sounds would occur between phonemes with shared features. This raises the question of whether the model really needs phonemes in addition to features. Phoneme units are needed to account for the fact that slips of phonemes are far more frequent than unambiguous slips of single features (Shattuck-Hufnagel, 1979; Shattuck-Hufnagel & Klatt, 1979; Stemberger, 1983). Models with both segmental and featural units can simulate error frequencies, but no model without segmental units has been able to do so (Dell, 1986). Although features were not the focus of these experiments, units for words, phonemes, and features are needed to provide a full account of the results.

Remarkably, nodes for units such as the rhyme are not required to account for our data. This result must be reconciled with other findings of rhyme effects, including evidence from speech errors and from word games showing that the rhyme is hard to disrupt while the CV is not. Our view is that the rhyme effects found in many experiments are important, but that they may arise from statistical imbalances in the vocabulary rather than from explicit rhyme units. In English, for example, particular rhyme sequences tend to recur to a greater extent than particular CVs, across the vocabulary as a whole (Dell et al., 1993). A general property of languages is that there tends to be less correlation between the sounds that comprise the onset and nucleus than between the nucleus and coda. There are greater phonotactic constraints on the content of the coda than on the onset (Clements, 1990; Goldsmith, 1990; Kenstowicz, 1994). In certain connectionist models, imbalances in the vocabulary have been shown to produce rhyme-like speech error effects (Dell et al., 1993) or a sensitivity to rhyme units in reading (Seidenberg & McClelland, 1989) without the use of explicit rhyme units. These models have the property that the processing of a particular word is influenced by all of the similar words in the vocabulary. This influence may be the mechanism for the rhyme's greater coherence, as reflected in a number of behavioral measures.

There are a couple of problems with this speculation, though. First, if rhyme effects are due to imbalances in the vocabulary, why were there no rhyme effects in our first experiment? It may be because there was no coherence between the vowel and the C_f in the local vocabulary of the experiment. The 32 CVCs in the materials had symmetric CV and VC units, and subjects had extensive practice with them, producing between 3000 and 4000 CVCs (from among the 32) in the practice session alone. There was no difference in the coherence of the CVs versus the rhymes in our materials, and subjects did not behave as though there was. In a vocabulary with more redundancy among rhymes or with less practice, one might expect this property of the larger English vocabulary to emerge.

The second problem with our attributing rhyme effects to statistical imbalances in the vocabulary is that this begs the question. Were do such imbalances come from in the first place? We are far from providing a complete answer to this question, but it is possible that a phenomenon like sequential cuing could be one of the forces creating the imbalance. The sequential cuing effect suggests that it is better to have more variety among sounds at the beginnings of adjacent words and more predictablility at the end. Since miscuing is costly, it may be better to have more shared material at the ends rather than at the beginnings of words, in general. That is, it may be easier to have the vocabulary as a whole be more like CAT, BAT, MAT, RAT (etc.) than like CAT, CAB, CAN, CAD. So our suggestion is not that the existing vocabulary shapes processing effects (although we believe that it does), nor that an a priori linguistic unit such as the rhyme shapes these effects. Instead, a production system that retrieves the sounds of words in sequence may exert a force on the vocabulary, introducing regularities at the ends of words and syllables, which then become part of the language that is there to be learned.

Processing constraints from the production side are probably not the only pressures that contribute to regularities at the ends of words. Recognition processes may also benefit from greater distinctiveness at the beginnings of words rather than at the end. In models of lexicals access, the initial part of a word strongly constrains the set of candidate words that compete for recognition (Marslen–Wilson, 1989; Zwitserlood, 1989). Both production and perception may exert similar pressures on the vocabulary, favoring greater distinctiveness near the beginnings of both production and recognition units. In a complete account of the representation of words, we need to consider how speakers and listeners shape the structure of the vocabulary in addition to how they are influenced by the structures that they receive as input.

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References

Berg, T. (1988). *Die Abbildung des Sprachproduktionsprozess in einem Aktivationsflussmodell.* Tuebingen: Max Niemeyer.

Bock, J.K. (1987). An affect of the accessibility of word forms on sentence structures. *Journal of Memory and Language, 26,* 119–137.

Butterworth, B., & Whittaker, S. (1980). Peggy Babcock's relatives. In G.E. Stelmach & J. Requin (Eds.), *Tutorials in motor behavior* (pp. 647–656). Amsterdam: North-Holland.

Clements, G.N. (1990). The role of the sonority cycle in core syllabification. In J. Kingston & M. Beckman (Eds.), *Working papers in laboratory phonology I: Between the grammar and physics of speech* (pp. 283–333). Cambridge, UK: Cambridge University Press.

Colombo, L. (1986). Activation and inhibition with orthographically similar words. *Journal of Experimental Psychology: Human Perception and Performance, 12,* 226–234.

Dell, G.S. (1984). Representation of serial order in speech: Evidence from the repeated phoneme effect in speech errors. *Journal of Experimental Psychology: Learning, Memory and Cognition, 22,* 222–233.

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

Dell, G.S. (1988). The retrieval of phonological forms in production: Tests of predictions from a connectionist model. *Journal of Memory and Language, 27,* 124–142.

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

Fowler, C.A. (1987). Consonant–vowel cohesiveness in speech production as revealed by initial and final consonant exchanges. *Speech Communication*, *6*, 231–244.

Fowler, C.A., Treiman, R., & Gross, J. (1993). The structure of English syllables and polysyllables. *Journal of Memory and Language*, *32*, 115–140.

Fromkin, V.A. (1971). The non-anomalous nature of anomalous utterances. *Language*, *47*, 27–52.

Garrett, M.F. (1975). The analysis of sentence production. In G.H. Bower (Ed.), *The psychology of learning and motivation* (pp. 231–255). New York: Academic Press.

Goldsmith, J.A. (1990). *Autosegmental and metrical phonology*. Oxford: Basil Blackwell.

Harley, T. (1984). A critique of top-down independent levels models of speech production: Evidence from non-plan-internal speech errors. *Cognitive Science*, *8*, 191–219.

Hayes, B. (1989). Compensatory lengthening in moraic phonology. *Linguistic Inquiry*, *20*, 253–306.

Houghton, G. (1990). The problem of serial order: A neural network model of sequential learning and recall. In R. Dale, C. Mellish, & M. Zock (Eds.), *Current research in natural language generation*. London: Academic Press.

Hyman, L.M. (1985). *A theory of phonological weight*. Dordrecht, Foris Publications.

Iverson, G. & Wheeler, D. (1989). Phonological categories and constituents. In R. Corrigan, F. Eckman, & M. Noonan (Eds.), *Linguistic categorization* (pp. 93–114). Philadelphia: John Benjamins.

Kenstowicz, M. (1994). *Phonology in generative grammar*. Cambridge, MA: Blackwell.

Kupin, S. (1979). *Tongue twisters as a source of information about speech production*. PhD dissertation, University of Connecticut.

Lehiste, I. (1970). *Suprasegmentals*. Cambridge, MA: MIT Press.

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

Levelt, W.J.M., Schriefers, H., Vorberg, D. Meyer, A.S., Pechmann, T., & Havinga, J. (1991). The time-course of lexical access in speech production: A study of picture naming. *Psychological Review*, *98*, 122–142.

Levin, J. (1985). *A metrical theory of syllabicity*. PhD dissertation, MIT.

Lupker, S.J., & Colombo, L. (1990). *Inhibitory effects in form priming: An evaluation of phonological contributions*. Paper presented at the 31st annual meeting of the Psychonomics Society.

MacKay, D.G. (1970). Spoonerisms: The structure of errors in the serial order of speech. *Neuropsychologia*, *8*, 323–350.

MacKay, D.G. (1972). The structure of words and syllables: Evidence from errors in speech. *Cognitive Psychology*, *3*, 210–227.

MacKay, D.G. (1974). Aspects of the syntax of behavior: Syllable structure and speech rate. *Quarterly Journal of Experimental Psychology*, *26*, 642–657.

MacKay, D.G. (1987). *The organization of perception and action: A theory for language and other cognitive skills*. New York: Springer–Verlag.

Marslen–Wilson, W.D. (1989). Access and integration: Projecting sound into meaning. In W.D. Marslen–Wilson (Ed.), *Lexical representation and process* (pp.3–24). Cambridge, MA: MIT Press.

Martin, N., Weisberg, R.W., & Saffran, E.M. (1989). Variables influencing the occurrence of naming errors: Implications for a model of lexical retrieval. *Journal of Memory and Language*, *28*, 462–485.

McCarthy, J.J., & Prince, A.S. (1986). *Prosodic phonology*. Unpublished manuscript, University of Massachusetts, Amherst, MA.

McCarthy, J.J., & Prince, A.S. (1990) Foot and word in prosodic morphology: The Arabic broken plural. *Natural Language and Linguistic Inquiry*, *8*, 209–283.

Meyer, A. (1991). The time course of phonological encoding in language production: Phonological coding inside a syllable. *Journal of Memory and Language*, *30*, 69–89.

Meyer, D.E., & Gordon, P.C. (1985). Speech production: Motor programming of phonetic features. *Journal of Memory and Language*, *24*, 3–26.

Nooteboom, S.G. (1969). The tongue slips into patterns. In A.G. Sciarone, A.J. van Essen, & A.A. van Raad (Eds.), *Leyden studies in linguistics and phonetics* (pp. 114–132). The Hague: Mouton.

O'Seaghdha, P.G., Dell, G.S., Peterson, R.R., & Juliano, C. (1992). Modelling form-related priming effects in comprehension and production. In R. Reilly & N.E. Sharkey (Eds.), *Connectionist approaches to language processing* (Vol. 1). Hillsdale, N.J.: Erlbaum.

Peterson, R. (1991). *A phonological competition model of form-related priming effects*. Doctoral dissertation, University of Rochester.

Peterson, R.R., Dell, G.S., & O'Seaghdha, P.G. (1989). A connectionist model of form-related priming effects. *Proceedings of the eleventh annual conference of the Cognitive Science Society*.

Rosenbaum, D.A. (1987). Successive approximations to a model of human motor programming. In G.H. Bower (Ed.), *The psychology of learning and motivation*. New York: Academic Press.

Rosenbaum, D.A., Inhoff, A.W., & Gordon, A.M. (1984). Choosing between movement sequences: A hierarchical editor model. *Journal of Experimental Psychology: General*, *113*, 372–393.

Rosenbaum, D.A., Weber, R.J., Hazelett, W.H., & Hindorff, V. (1986). The parameter remapping effect in human performance: Evidence from tongue twisters and finger fumblers. *Journal of Memory and Language*, *25*, 710–725.

Seidenberg, M.S., & McClelland, J.L. (1989). A distributed developmental model of visual word recognition and naming. *Psychological Review*, *96*, 523–568.

Shaffer, L.H. (1976). Intention and performance. *Psychological Review*, *83*, 375–393.

Shattuck-Hufnagel, S. (1979). Speech errors as evidence for a serial-order mechanism in sentence production. In W.E. Cooper & E.C.T. Walker (Eds.), *Sentence processing: Psycholinguistic studies presented to Merrill Garrett*. Hillsdale, NJ: Erlbaum.

Shattuck-Hufnagel, S. (1983). Sublexical units and suprasegmental structure in speech production planning. In P.F. MacNeilage (Ed.), *The production of speech* (pp. 109–136). New York: Springer-Verlag.

Shattuck-Hufnagel, S. (1986). The representation of phonological speech information during speech production: Evidence from vowel errors in spontaneous speech. *Phonology Yearbook*, *3*, 117–149.

Shattuck-Hufnagel, S. (1987). The role of word-onset consonants in production planning: New evidence from speech error patterns. In E. Keller & M. Gopnik (Eds.), *Motor and sensory processes of language* (pp. 17–47). Hillsdale, NJ: Erlbaum.

Shattuck-Hufnagel, S. (1992). The role of word structure in segmental serial ordering. *Cognition*, *42*, 213–258.

Shattuck-Hufnagel, S., & Klatt, D.H. (1979). The limited use of distinctive features and markedness in speech production: Evidence form speech error data. *Journal of Verbal Learning and Verbal Behavior*, *18*, 41–55.

Stemberger, J.P. (1983). *Speech errors and theoretical phonology: A review*. Bloomington, IN: Indiana Linguistics Club.

Stemberger, J.P. (1985). An interactive activation model of language production. In W.W. Ellis (Ed.), *Progress in the psychology of language* (Vol. 1). Hillsdale, NJ: Erlbaum.

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

Sternberg, S., Monsell, S., Knoll, R.L., & Wright, C.E. (1978). The latency and duration of rapid movement sequences: Comparisons of speech and typewriting. In G.E. Stelmach (Ed.), *Information processing in motor control and learning* (pp. 117–152). New York: Academic Press.

Treiman, R. (1983). The structure of spoken syllables: Evidence from novel word games. *Cognition*, *15*, 49–74.

Treiman, R. (1986). The division between onsets and rimes in English syllables. *Journal of Memory and Language*, *25*, 476–491.

Treiman, R., & Danis, C. (1988). Syllabification of intervocalic consonants. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *14*, 145–152.

Yaniv, I., Meyer, D.E., Gordon, P.C., Huff, C.A. & Sevald, C.A. (1990). Vowel similarity, connectionist models, and syllable structure in motor programming of speech. *Journal of Memory and Language*, *29*, 1–26.

Zwitserlood, P. (1989). The locus of sentential-semantic context in spoken-word processing. *Cognition*, *32*, 25–64.