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SERIAL ORDER REVISITED: A REPLY TO R. D. KENT

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This paper examines two rule-based or non-associative alternatives to associative theories of serial order in behavior. Both rule-based models seemed superior to chain association, but one, the CV Organization model, was found to require further development to handle corollary issues associated with serial ordering eg. coarticulation phenomena, sequential plasticity and a parsimonious fit to speech rate data. The other rule-based model, Syllabic Recording, was shown to be compatible with these and several previously unexplored corollary issues, including the nature of sequential redundancy, production variability (word reduction) and the nature of errors in the acquisition of phonology by children.

Serial ordering poses important theoretical challenges. The core question is how we store and generate ordered sequences of action; in the case of speech, ordered sequences of vocal tract positions for syllables or words and ordered sequences of words for sentences. This core question interacts with several corollary issues and a successful theory must also explain serial order perception, speech errors, co-articulation phenomena, serial order acquisition, sequential plasticity seen in word games such as pig Latin, and linguistic facts such as the nature of sequential redundancy.

The core problem admits two general classes of solution: associative and non-associative. Associative solutions postulate unidirectional bonds for linking one motor unit to another such that firing one unit triggers the next in sequence. Non-associative models postulate no direct links between motor units, which are triggered in sequence by, say, serial order rules.

Either associative or non-associative principles provide an adequate solution to the core problem taken in isolation, although Lashley's (1951) arguments against *phonemic* associative models still hold (cf. Wickelgren's (1976) allophonic associative model). But the core problem cannot be examined in isolation and corollary problems such as speech errors, sequential redundancy and any form of linguistic creativity seem to provide insurmountable difficulties for associative theories.

On the other hand, chain association seems simple and general, and no non-associative theory of comparable scope has ever emerged. It is as a non-associative alternative that Kent's (1975) CV Organization hypothesis warrants close attention and perhaps further development along with MacKay's (1972) Syllabic Recoding hypothesis. As nonassociative models, similarities outweigh differences between CV Organization and Syllabic Recoding. Both postulate a hierarchy of functional

favour Syllabic Recoding. Consider parsimony. Models compared for parsimony must perform identical functions by means of comparable and enumerable steps or assumptions. But CV Organization and Syllabic Recoding are incomparable in several ways. Kent includes rules such as S → s ø t i which summarize preceding rules rather than performing unitary syntagmatic operations. As a second source of incomparability, Kent omits paradigmatic rules required of a viable speech production device. With paradigmatic rules added and summary rules omitted as in Table I, CV Organization requires 13 levels of complexity for explaining the data at hand. Syllabic Recoding requires only eight.

Next syllable sequences. Syllabic Recoding represents syllable sequences as S1, S2, S3, etc., whereas CV Organization requires a new set of terms, say Sx, Sy, Sz, etc. for representing syllable sequences, since S1, S2, etc. have already been used in representing CV subunits. Again Syllabic Recoding seems simpler.

Fits with the data are incomparable for the two models because of an inconsistency in representing CV Organization rules. Kent expands S as CV for V structures, but not for CV and other surface structures. Perhaps Kent is following a shorthand principle of omitting universal rules which apply for all syllables but if so he should state this principle and follow it consistently. Finally it should be stressed that existing data neither support the hypothesis that CV *surface* structures are special nor contradict the hypothesis that V and CV syllables have identical underlying structures as postulated in MacKay (1973).

Lack of development is the main shortcoming of CV Organization as well as other models. Associative and non-associative models have yet to address corollary problems such as production variability (as seen in word reductions such as DI JA for DID YOU) and phonological redundancy. Syllabic Recoding promises a solution to these outstanding problems, but alternative solutions should be developed and subjected to experimental test.

Under Syllabic Recoding, production variability as in word reductions such as GOVNOR for GOVERNOR reflects either optional recoding rules or incomplete specification of a standard set of recoding rules (due to time pressure for example). The model predicts that later rather than earlier rules in a recoding hierarchy (e.g., Final Consonant Group expansion) will be omitted in the process of incomplete expansion. Moreover omitted or reduced segments should constitute natural units in the model: reductions involving non-constituents such as final consonant of one syllable and initial consonant of the next, e.g., BOTER for BOLSTER should be rare.

Syllabic Recoding represents sequential redundancy by two types of rules: lexical recoding rules for specifying nonredundant features and phonological rules for adding redundant features. Lexical rules are stored as part of a word engram, while phonological rules are stored independently of particular words and apply wherever possible to every syllable in the language. For example, Initial Consonant Group for a word such as SPAIN may be stored as an unordered, minimally redundant set of features [stop] [fricative] [+ front], which phonological rules expand automatically as the ordered feature sets [fricative] [alveolar] [unvoiced], [stop] [frontal] [unvoiced]. Such a solution has interesting implications for the acquisition of phonology by children. The main problem of the child acquiring

units specified by rule. The "surface" units resemble phonemes or sets of distinctive features and provide instructions for generating the sequence of vocal tract configurations. "Underlying" units include abstract constituents such as the syllable, which may or may not receive direct manifestation at the surface level. This viewpoint contrasts with associative models such as Wickelgren (1976) where syllables *per se* do not exist as units but only syllable junctures which operate like segments at the surface level. Both Syllabic Recoding and CV Organization postulate null elements with no necessary surface realization. Null expansion is an attractive mechanism not just for syllables but for other levels as well. Consider for example the morphological level and in particular derivatives or morphological variants such as BOMBARD or BOMBARDIER which contain an entire segment (B) not manifest in the stem (BOMB). Null expansion is a useful derivational device for dealing with "silent segments" which only become manifest in certain morphological environments as in this and other examples such as SIGN–SIGNAL PARADIGM–PARADIGMATIC, KNOWLEDGE–ACKNOWLEDGE, DAMN–DAMNATION.

Empirically, both models provide an acceptable fit to speech rate data and correctly predict that bisyllabic inputs of the form VCV are more readily perceived as V–CV than as VC–V using Warren and Gregory's (1958) verbal transformation technique.

Now the differences. Whereas both models postulate underlying constituents, they postulate different constituents. As an example, CV Organization postulates (CV) (C) structure for CVC syllables whereas Syllabic Recoding postulates (C) (VC). The latter structure is compatible with data on phonological similarity (rhyming), tongue twisters, speech errors and sequential redundancy (sequential constraints within syllables being greater between vowel and final consonants than between vowel and initial consonants).

Kent mentions differences in parsimony, in treatment of syllable sequences and in detailed fit with speech rate data. Upon close inspection, these differences

TABLE I

Syntagmatic and paradigmatic rules for VC, V and VCCC syllables under the CV Organization hypothesis

VC syllable [is]	V syllable [i]	VCCC syllable [amps]
(1) $S \rightarrow S_1 + S_2$	(1) $S \rightarrow CV$	(1) $S \rightarrow S_1 + S_2 + S_3 + S_4$
(2) $S_1 \rightarrow CV$	(2) $C \rightarrow \phi$	(2) $S_1 \rightarrow CV$
(3) $C \rightarrow \phi$	(3) $V \rightarrow i$	(3) $C \rightarrow \phi$
(4) $V \rightarrow i$		(4) $V \rightarrow a$
(5) $S_2 \rightarrow CV$		(5) $S_2 \rightarrow CV$
(6) $C \rightarrow \phi$		(6) $C \rightarrow m$
(7) $V \rightarrow s$		(7) $V \rightarrow \phi$
		(8) $S_3 \rightarrow CV$
		(9) $C \rightarrow p$
		(10) $V \rightarrow \phi$
		(11) $S_4 \rightarrow CV$
		(12) $C \rightarrow S$
		(13) $V \rightarrow \phi$

English phonology is not what features distinguish one word from another, but which of the many features in a word are non-redundant and must therefore be recoded as lexical rules and which are redundant or generated by phonological rules applying to all words of the language. Consider for example the phonological rule whereby clusters of two or more non-sonorants (affricates, fricatives or stops) must agree in voicing. Based on an impoverished sample of words, say SPIN, STAY, SKIN, BLUE, DRY, GREEN, the child might formulate the inaccurate rule that all clusters agree in voicing, thereby accounting for the phenomenon that children well beyond the babbling stage sometimes produce segments extraneous to their language, e.g., voiceless nasals (S̥MITH) and voiceless liquids (S̥LIP) (cf. Smith, 1973). Inadequately formulated redundancy rules may also explain the general phenomenon of context-dependent phonological errors in children (cf. MacKay, 1970). In this view, context-dependent phonological errors reflect inaccurate redundancy rules, rather than inaccurate phoneme classes (Winitz, 1969) or inadequate muscular control (Falk, 1973) or inappropriate transformational rules such as "delete initial S" (Smith, 1973).

In conclusion, the serial order problem apparently is approaching a fruitful stage where detailed alternative models are being developed, extended to corollary problems that Lashley (1951) discussed, and hopefully subjected to experimental test.

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