COMPUTER-ASSISTED NATURAL PROCESS ANALYSIS (NPA): RECENT ISSUES AND DATA

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Several procedures for analyses of children's speech became available in the early 1980s (Crystal, 1982; Grunwell, 1982b; Hodson, 1980; Ingram, 1981; Klein, 1982; Shriberg and Kwiatkowski, 1980; Weiner, 1979). Central to these approaches is an attempt to capture the principles underlying normal or delayed speech development, rather than to describe the articulatory or acoustic phonetic details of individual errors. The term "phonological process" is proposed to capture one aspect of such principles, with researchers taking markedly different views on how the construct should be defined and operationalized for the purposes of phonetic and phonologic assessment. Relevant validity and reliability issues have received considerable attention (see representative reviews in Bernthal and Bankson, 1981; Dunn, 1982; Edwards and Shriberg, 1983; Hanson, 1983).

The beginning of the decade also marked the onset of widespread interest in microcomputers and in software for speech analysis. This issue on phonologic assessment affords us the opportunity to review findings on one procedure, Natural Process Analysis (NPA) (Shriberg and Kwiatkowski, 1980) that recently has been "brought up" as part of a software package (Shriberg, 1982a). In this article, we hope both to clarify and extend the principles previously described by us (1980) and, more broadly, to address issues in phonetic and phonologic assessment. The article is structured as a series of questions organized into three topic areas: natural phonological processes, continuous speech samples, and computers. Findings from both published and as yet unpublished studies will be cited, as they relate to selected validity and reliability issues in NPA.

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NATURAL PHONOLOGICAL PROCESSES

How Should Natural Phonological Processes Be Used In Phonologic Analyses?

Among the units that have been proposed to describe normal and disordered speech, the natural phonological process (Stampe, 1973) appeared to us to have the potential to bridge the "organic-functional" dichotomy in clinical speech pathology. We interpreted Stampe to have observed that (1) some speech sounds are more natural than others, and (2) less natural sounds may be deleted or replaced when certain perceptual, cognitive, articulatory, or social conditions motivate sound change.

Some obvious questions about Stampe's two premises are: How is *naturalness* determined across speech sounds in languages of the world? What levels of cognitive-linguistic processing underlie natural deletion and replacement phenomena? Do listeners or speakers actually "use" a process to simplify speech perception (for example, see Macari, 1978) or speech production tasks? That is, does the construct of natural processes have psychological reality, or do such deletion and replacements occur at mechanism levels independent of psycholinguistic processing? Ohala's (1974) query of Stampe remains at the heart of the matter: Are phonological processes software or hardware constraints? Theoretical discussions and methodological studies have been concerned with such definitional matters and with the logical operations necessary to operationalize phonological processes in assessment paradigms (for example, see Dinnsen et al., 1980; Dunn, 1982; Edwards, 1982; McReynolds and Elbert, 1981).

Throughout the sometimes heated controversy over the validity of the construct, our interest in applying natural phonological processes to specific research questions has remained as proposed in 1980. We were intrigued by the possibility that naturalness concepts might be useful for the purposes of diagnosis. Whereas the *natural* speech sound errors of young normally speaking children might attest to intact speech processing mechanisms, the same errors in older children and certain *non-natural* errors may be diagnostic of speech processing constraints. For an example of non-natural sound changes, nasal emission errors should prompt a clinician to suspect problems in velopharyngeal function (that is, "organic" errors). Other types of non-natural speech errors might eventually be associated with cognitive-linguistic or psychosocial constraints (that is, "functional" errors).

Unfortunately, we suspect that neither the diagnostic goal of the NPA nor our particular operational definitions for natural phonological processes were clearly communicated by us (1980). Weismer (in press), for example, in his excellent tutorial on uses of acoustic records to augment perceptual data, excerpts the following from *Natural Process Analysis (NPA)* (1980):

> The term *natural process* moves beyond description to an explanatory-level account of sound change . . . for clinical needs too, processes may have the conceptual and methodological adequacy that to date, neither segmental analyses . . . structural analyses, . . . featural analyses, . . . or generative phonological analyses . . . have been able to achieve.

Weismer makes the following comment on this excerpt:

> We believe, however, that this kind of phonological process analysis suffers from the same kind of descriptive and explanatory weakness which is thought to characterize traditional analyses. Thus when a child omits final consonants, attributing the errors to a 'phonological process of final consonant deletion' does no more to explain partial neutralization—as revealed by vowel duration or format trajectory analyses—than the traditional description of 'omitted final consonants.'

What apparently was not explicit in *Natural Process Analysis (NPA)* (1980) is that the descriptive-explanatory power is not purported to be in the occurrence of a process; rather, explanation will reside, we hope, in eventual findings that only *certain children* have frequent occurrences of certain sound changes. Final consonant deletion errors, for example, have frequently been described as prevalent in the speech of children with intellectual deficits (Bodine, 1974; Braun and Fry, 1983; Stoell-Gammon, 1980). Whether final consonant deletions occur in such children because of perceptual, cognitive, or articulatory constraints is an intriguing and experimentally feasible research question, but one that is most efficiently undertaken pending the results of correlative-descriptive work (Shriberg, 1982b).

Another basic concern that has been raised about the validity of NPA procedures is whether one instance of a consonant deletion or substitution in a speech sample constitutes the occurrence of a natural phonological process (for example, see McReynolds and Elbert, 1981; Schwartz, in press). In our view, quantitative criteria for determining process occurrence address only *reliability* concerns. Data certainly could be unreliable if based on only one instance of a sound substitution that meets the definition for a natural process. A section of noisy tape or some other stimulus or transcriber variable could yield an unreliable transcription of a sound change. It seems safe to assume that one occurrence of any type of behavior will be viewed clinically with conservative judgment.

The *validity* of using such terms as "Stopping," however, to describe the singular occurrence in a sample of a stop for a fricative is independent of quantitative, productivity criteria, such as those used to determine when a child "uses" a syntactic rule. This is the very distinction between process and rule that often has been confused by writers who favor a generative view of all sound change phenomena. We prefer to hold to Stampe's proposal that "hardware" constraints underlie the occurrence of certain (natural) sound changes, whereas other aspects of phonological performance are mediated by rule learning, for example, morphophonemic rules. The NPA approach deliberately obviates the need for abstract phonological levels, complex derivations (that is, rule ordering, constitutent processes), and inductive reasoning based on selected sections of a transcript. Rather, every occurrence of a sound change that meets one of eight simple definitional criteria is considered to reflect persistent or momentary constraints (such as an assimilative slip of the tongue in adult speech) involving perceptual, cognitive, or articulatory naturalness. By design, the procedure attempts to gain psychometric rigor by reducing to a minimum, abstract notions, such as what a child or adult "knows," "avoids," "uses," or "prefers." Finally, the argument for arbitrary, quantitative criteria for process terminology is reminiscent of the classic problem of how many hairs constitute a beard: At what point does a child who previously stopped all fricatives become a nonstopper? From our definitional perspective, as the child improves in therapy and the percentage of Stopping approaches zero, the child simply is stopping fricatives less often.

To summarize, we view the concept of a natural phonological process as a potentially useful cover term for sound changes motivated by perceptual, cognitive, or articulatory naturalness. We leave to experimental phoneticians and phonologists the search for explanations and a universal metric of naturalness. Our research goal with speech-delayed children since publishing *Natural Process Analysis (NPA)* (1980) has been to explore the validity of the view that speech sound changes are not all alike—that the occurrence of both natural and unnatural sound changes may be diagnostic of their causal origins.

ARE EIGHT NATURAL PROCESSES ADEQUATE TO DESCRIBE THE SOUND CHANGES SEEN IN NORMAL AND DELAYED SPEECH ACQUISITION?

NPA's use of only eight natural processes to categorize individual segment errors has been criticized on the grounds that more process terms are needed to cover *all* the sound changes seen in normal and delayed acquisition of speech. For example, Grunwell (1982a) states: "Only eight processes are analyzed. . . . As a result of such a restricted list many 'substitutions' in clinical data would be uncodable using NPA." Again what apparently is misunderstood is that the formal part of the NPA procedure is expressly constructed to yield "uncodable" data. Simply to label every type of speech error with a process term, as indeed other analyses procedures have sought to do, seems to us to be unrevealing, if not unfounded. Rather, the NPA yields data on eight sound change categories that assumedly comprise "natural" deletions and replacements. Rationale for coding only these eight categories includes several types of validity and reliability concerns (Shriberg and Kwiatkowski, 1980). The assessment procedure for a given child is organized to yield answers to two questions: (1) what is the relative occurrence of the eight sound changes and the bases for error type variability within each sound change, and (2) what is the relative occurrence and nature of all other "uncoded" sound changes?

To determine whether the eight natural phonological process categories are adequate to describe normal speech acquisition, Hoffmann (1982) obtained continuous speech samples from 72 normally developing 3- to 6-year-old children. The methodology for sampling is described later in this article in the context of methodological studies. The audio-taped speech samples were transcribed by consensus and transcripts were entered and processed by a software package that included an NPA option. Figure 1 is a profile of the mean percentage of occurrence of each of the eight natural processes for all 72 children. Represented by the left and center bars in Figure 1 are the percentages

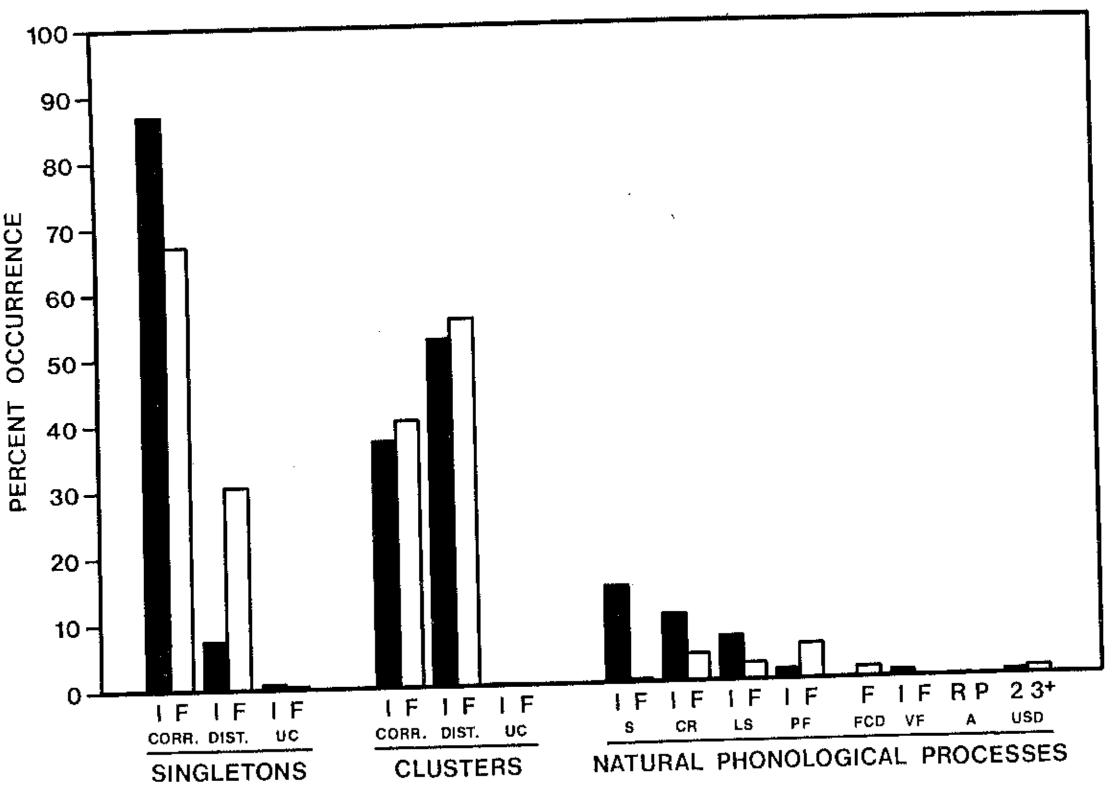


Figure 1. Percentage of occurrence of eight natural phonological processes in 72 3- to 6-year-old children with normally developing speech. I: Initial; F: Final; CORR: Correct; DIST: Distortion; UC: Uncoded; S: Stopping; CR: Cluster Reduction; LS: Liquid Simplification; PF: Palatal Fronting; FCD: Final Consonant Deletion; VF: Velar Fronting; A: Assimilation: Regressive, Progressive; USD: Unstressed Syllable Deletions: 2 syllable; 3 or more syllable.

of occurrence of sounds that were correct, distorted, and uncoded in word-initial and word-final singletons and clusters. Uncoded sound changes, as described later, are those deletion and substitution errors that do not meet the criteria for one of the other eight sound change categories. As shown in Figure 1, the most frequently occurring natural process sound changes are coded as Stopping, Cluster Reduction, and Liquid Simplification. Sound changes that meet coding criteria for the other five process categories are less frequent.

For the present discussion, what is important in these normative data is that the average uncoded sound changes across age groups totalled less than 2 percent of the singleton and cluster consonant data for monosyllabic words. (Approximately 20 percent of words are mutisyllabic and, hence, coded only for unstressed syllable deletion; rationales for this decision are given in *Natural Process Analysis (NPA)* [1980]). These normative data support the position that the eight phonological processes included in NPA are adequate to describe most speech errors of normally developing 3- to 6-year-old children. It is clear from the literature, however, that below the age of 3 years, the speech of normally developing children does include deletions and substitutions that cannot be adequately captured by these eight sound change categories (for example, see Irwin and Wong, 1983; Schwartz et al., 1980).

We also have reported findings for two samples of speech-delayed children (Kwiatkowski and Shriberg, 1983; Shriberg and Kwiatkowski, 1982). These data also support the descriptive adequacy of the eight sound change categories. Figure 2 includes data for the more recent sample arranged in the same format as the data for the normative sample. Note that for the sound changes of these speech-delayed children, a total average of less than 8 percent of singleton and cluster consonants in monosyllabic words are uncoded.

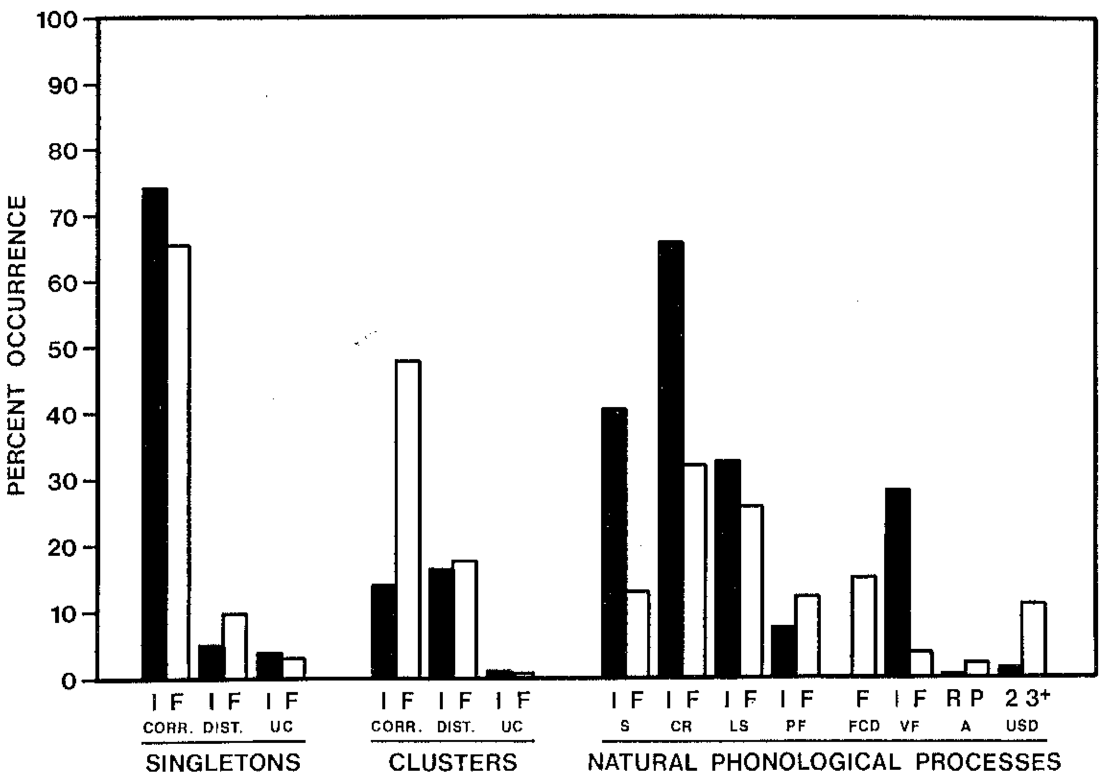


Figure 2. Percentage of occurrence of eight natural phonological processes in 38 3- to 10-year-old children with delayed acquisition of speech. See Figure 1 for key to the abbreviations.

Have Any Etiological Subclasses Been Identified by Natural Phonologic Process Analysis?

The basic goal of NPA, as developed previously, is to inventory a child's phonetic behaviors and sound changes to determine whether or not all errors are "natural." Because to date we have concentrated on methodological issues, this section is essentially only a progress report. Two large group studies have been reported (Kwiatkowski and Shriberg, 1983; Shriberg and Kwiatkowski, 1982), and a cross validation study from a third clinical site is in progress (Shriberg et al., in preparation). Subgroup studies on several types of children have been initiated in four areas: those with hearing, speech motor performance, craniofacial, and psychosocial involvement. We view the results of these studies as only suggestive.

Data presented in Shriberg and Smith (1983) support the hypothesis that certain uncoded sound changes occur frequently in speech-delayed children who have a history of recurrent otitis media and another study (Shriberg et al., in preparation) will assess the prevalence of these sound changes in 35 normally developing children.

Computer-assisted NPA has also been used to sort the errors of children labeled "apractic" (Shriberg and Aram, in preparation). In this possible subgroup, the percentage of uncoded errors is markedly greater than the percentage that occurs in an undifferentiated group of "functional" speech disorders. Interestingly, our preliminary data indicate that children with histories of middle ear involvement and those with possible apractic speech have similar proportions of natural process errors and some similar types of uncoded errors. For example, in some children in both study groups we observed the tendency for slight on-glides before word-initial /w/, that is, [^{ə}w]. For the middle ear children, one could view an on-glide as evidence of incomplete establishment of the correct underlying features for the glide /w/ in word-initial position, that is, a problem with adult, ambient forms. For the apractic child with the apparently same phonetic behaviors, however, an on-glide more plausibly could reflect speech motor imprecision (Kent and Rosenbeck, 1983). Close acoustic analysis of these perceptually similar errors may eventually suggest that their phonetic and phonologic origins are different.

To summarize, the validity of the NPA approach will ultimately lie in its ability to sort and differentiate the sound changes of speech-delayed children. In turn, the utility of diagnostic labels, such as motor speech involved, middle ear involved, or psychosocially involved, will need to be assessed by management approaches that operationalize the relevant differences in historical and maintaining causes.

CONTINUOUS SPEECH SAMPLES

Unassisted and computer-assisted NPA requires a sample of continuous speech, whereas other procedures use spontaneous or imitated words (Hodson, 1980), delayed imitation (Weiner, 1979), or any type of speech sample (Ingram, 1981). The decision to base NPA on continuous speech samples was made following pilot studies using words (citation forms) and delayed imitation procedures. We found that such approaches yielded data that differed from continuous speech data for certain children and certain sound changes (Shriberg and Kwiatkowski, 1980). A continuous speech, open set approach required that conventions be developed for dealing with diverse children, glossing unintelligible words, transcribing casual speech forms, and many other technicalities.

Two interdependent concerns have been raised about the use of continuous speech samples: (1) do sampling conditions affect the phonetic and phonologic data and (2) does word type versus word token coding affect the phonetic and phonologic data?

DO SAMPLING CONDITIONS AFFECT PHONETIC AND PHONOLOGIC DATA?

Six general procedures for obtaining a continuous speech sample are suggested by Shriberg and Kwiatkowski (1980), but data are not provided to support the contention that they will yield comparable speech samples. Availability of the computer-assisted NPA allowed us to examine closely the possible influence of subtle differences in sampling procedures on phonetic and phonologic analyses. Specifically, we wondered whether differences in stimulus materials or examiner prompts might ultimately affect the representativeness of the speech data. The results of a study to explore these questions (Kwiatkowski and Shriberg, in preparation) are summarized here.

Method

Two female examiners sampled the speech of 6 speech-delayed children using five different sampling conditions. The six girls and six boys tested ranged in age from 2 years, 10 months to 5 years, 3 months.

Table 1 is a description of the five sampling conditions. The primary difference among conditions is that questions were not used to evoke responses in the two nondirected conditions, whereas they were used freely to evoke responses in the three directed conditions. The use of questions might affect a child's speech in two ways. First, questions remind a child that he or she is communicating with another person, which could motivate a child to use a "talk to another" register, rather than the "talk to oneself" register that often is used when children talk about play objects. Second, the use of questions allows an examiner to control the content of the child's utterances, which might result in an increase in the overall number of intelligible (that is, glossable) words.

The examiners followed explicit directions regarding how to prompt and respond to a child in each of the five conditions. The five speech samples lasting approximately 8 minutes each were obtained during a 45-minute session, with elicitation conditions balanced across children. The recorded samples were transcribed by the examiner who obtained the sample. Each examiner had had extensive training in the use of a clinical system for narrow phonetic transcription (Shriberg and Kent, 1982). Transcripts were pre-

TABLE 1. Description of Five Sampling Conditions to Evoke Continuous Speech for Phonetic and Phonologic Analyses*

Sampling Condition	*Type of Continuous Speech*	*Control of Content*	*Selection and Type of Stimulus Materials*	*Examiner's Comments/ Prompts*
I	Nondirected	Uncontrolled	Child-selected assorted materials and topics	Limited to nondirective comments
II	Nondirected	Indirect	Examiner-selected, single material: colorform Muppet setup.	Limited to nondirective comments relating to stimulus material
III	Directed	Indirect	Examiner-selected, single material: colorform house setup, including words containing all consonant sounds	Examiner may use both questions and comments to prompt verbalization about stimulus materials
IV	Directed	Direct	No materials	Examiner asks questions to identify topics child will talk about
V	Directed	Direct	Examiner-selected materials: pictures in a book; words and themes selected to evoke all consonant sounds	Examiner follows a script of questions appropriate to the pictures

* The five conditions are presumed to range from least to most directed types of continuous speech samples.

pared in accordance with guidelines for a software program termed PEPPER (Programs To Examine Phonetic and Phonologic Evaluation Records) (Shriberg, 1982a) that includes NPA as an output option.

Results

The results of repeated-measures analyses of variance on several dependent variables of interest may be summarized here as the responses to three questions.

Do Sampling Conditions Affect the Intelligibility of a Child's Speech? We use the percentage of glossable words in a continuous speech sample as an index of a child's intelligibility (with due consideration of the many sources of variance associated with intelligibility). Percentage of glossable words for the children in this study did not differ significantly by condition, ranging from 66 to 75 percent across the five sampling conditions. Moreover, analyses of individual child data indicate that actual differences in percentage of intelligible words over the five conditions were generally small. The group trends were logically consistent with the expected affects on speech of the different stimulus conditions and examiner questions. The least controlled speech samples (Table 1, Conditions I, II) yielded the lowest mean percentage of intelligible words (66 percent), whereas the most controlled condition (Condition V) yielded the highest percentage of intelligible words (75 percent).

These data suggest that sampling procedures such as those used in this study can be used effectively to obtain continuous speech samples from even severely speech-delayed children. They also suggest that intelligibility can be increased by increasing control over the content of the child's utterances by the use of controlled stimuli and direct questioning. For those children whose percentage of glossable words falls below approximately 66 percent or less than two out of every three words, we typically shift to a more controlled sampling procedure.

Do Sampling Conditions Affect the Frequency of Occurrence of Intended Consonants? Here we inspect trends among the 48 (2 examiners × 24 consonants) separate analyses run on the sampling conditions data. Frequency of occurrence for most consonants was similar across sampling conditions. Only a few consonants were statistically more or less frequent in one of the five conditions for one or both examiners. For both examiners, the sound /m/ occurred more frequently in free conversational samples (Condition IV), evidently as a function of children talking more about their own experiences (*me, my, mine,* and variants of *mom*). Also in these free conversational samples, there were statistically fewer occurrences of /ð/ for both examiners, plausibly due to the absence of physical referents and materials that are associated with a child's use of the demonstrative pronouns *this*, *that*, *those*, and *these* and the pronoun *them*.

Table 2 includes frequency of consonant occurrence data that support the findings reviewed above and those reported elsewhere (Shriberg, 1982b; Shriberg and Kwiatkowski, 1980, 1982). The first four data columns in Table 2 include findings from 3- to 9-year-old children with normally developing speech; the next two columns include data from children of the same age, but with speech delays; the final column includes data from the most recent adult study of consonant occurrence in continuous speech. The ranked and averaged percentage of occurrence for each consonant across the seven studies are given in the first three columns. There is remarkably good agreement in the proportional occurrence of these 24 English consonants, given differences across the studies associated with topics, examiner behaviors, age of subjects, speech status of subjects, and several important differences in the manner in which sounds were categorically assigned and tabulated (for example, stop allophones, /r/ allophones, syllabic sounds). Pearson correlation coefficients among the seven studies range from 0.84 to 0.98.

TABLE 2. Percentage of Occurrence of (Intended) English Consonants in Continuous Speech

Sound	Mean Rank	Mean %	*Hoffmann (1982)*	*Irwin and Wong (1983)**	*Carterette and Jones (1974)*	*Mader (1954)*	*Shriberg and Kwiatkowski (1982)*	*Shriberg and Kwiatkowski (1983)*	*Mines et al. (1978)*
n	1	12.01	11.22	9.84	13.63	13.14	11.7	13.04	11.49
t	2	11.83	12.43	14.05	7.91	11.74	13.7	13.08	9.88
s	3	6.90	6.78	6.66	6.94	6.50	7.1	6.43	7.88
r	4	6.68	7.06	5.99	8.20	7.83	5.2	5.84	6.61
d	5	6.41	4.26	6.89	6.31	10.25	5.8	5.33	5.70
m	6	5.93	5.20	5.52	7.49	4.63	5.6	7.97	5.11
z	7	5.36	8.69	4.88	4.58	3.70	3.0	3.97	4.70
ð	8	5.32	6.90	6.04	4.42	6.40	4.1	4.04	5.37
l	9	5.25	3.42	5.41	4.96	5.55	5.6	5.59	6.21
k	10	5.13	4.60	5.20	4.96	4.25	6.0	5.57	5.30
w	11	4.88	4.19	4.70	5.57	5.33	4.8	4.79	4.81
h	12	4.38	7.47	5.17	3.37	3.33	4.2	4.97	2.23
b	13	3.28	2.84	3.40	3.18	2.97	3.5	3.92	3.24
p	14	3.12	2.98	3.12	2.12	2.73	3.9	3.90	3.07
g	15	3.08	3.93	3.29	2.90	2.38	4.1	2.93	2.02
f	16	2.07	2.38	1.64	2.21	1.83	2.4	1.37	2.65
ŋ	17	1.58	.94	1.86	1.05	1.61	2.5	1.24	1.85
j	18	1.56	1.22	1.49	1.41	0.77	2.2	1.94	1.87
v	19	1.52	1.03	1.46	1.64	1.91	1.2	0.42	2.97
ʃ	20	0.93	0.87	1.14	0.84	0.84	1.5	0.38	0.95
θ	21	0.89	0.59	0.84	1.03	0.93	0.9	0.76	1.19
dʒ	22	0.58	0.62	0.50	0.53	0.69	0.6	0.19	0.95
tʃ	23	0.55	0.34	0.31	0.51	0.55	0.7	0.56	0.85
ʒ	24	0.03	0.01	0.01	0	0.01	0	0	0.15

* Data calculated from page 156, Table 8.4 to reflect only children aged 3, 4, and 6 years.

For the purpose of NPA or other phonologic analysis procedures based on continuous speech, several aspects of the data in Table 2 require comment. First, these group data indicate that in children older than 3 years of age, continuous speech samples yield stable distributional frequencies of consonants. However, children younger than 3 years and children with severe language production delays will have different distributional frequencies (see Irwin and Wong [1983] for detailed data on 18- and 24-month-old children). Second, notice that in comparison to children, adults have only somewhat higher proportions of the infrequently occurring sounds in the lower portion of Table 2. These six to eight sounds are simply infrequent in conversation, whatever the topic or age. We have found that a sample containing approximately 90 word types will yield frequency of occurrence data similar to the distributions in Table 2 (Shriberg and Kwiatkowski, 1982). However, the type of sampling conditions (see Table 1) and individual differences among children will determine the length of time needed to obtain a structurally representative sample.

DO SAMPLING CONDITIONS AFFECT PERCENTAGE OF OCCURRENCE OF NATURAL PHONOLOGIC PROCESSES? Computer-assisted NPA provides detailed percentage of occurrence output for each of the eight natural processes coded in the speech sample. Results of 15 analyses of variance (word-initial, word-final) indicated no significant differences in the percentage of occurrence of natural processes among the five sampling conditions.

To summarize, the findings reviewed in this subsection support the use of a variety of procedures to obtain a continuous speech sample for the purposes of unassisted or computer-assisted NPA. These data suggest that stimulus materials and clinician questions may affect the frequency of occurrence of certain lexical items and, hence, the frequency of occurrence of certain consonants. We generally inspect the percentage of intended occurrence of the 24 consonants (available as output in the computer-assisted NPA) before proceeding with phonetic and phonologic analyses. If there is a significant discrepancy from the distributions in Table 2, we use only word *types* for the analyses (as discussed in the next section) or we consider the sample invalid. What has seemed consistent in repeated sampling of more than 100 children with mild to severe speech delays is that the examiner must be extremely sensitive to a child's affective state on any given sampling occasion and should adjust sampling conditions as needed to maintain the child's interest or increase intelligibility. We assume that the task of obtaining a structurally stable speech sample for phonetic and phonologic analysis requires the same level of interactive skills needed to obtain other data in speech-language and hearing assessment. In Kwiatkowski and Shriberg (in preparation), specific guidelines are suggested for obtaining representative continuous speech samples for the purpose of phonetic and phonologic analyses.

Does Type Versus Token Sampling Affect Natural Process Analyses Data?

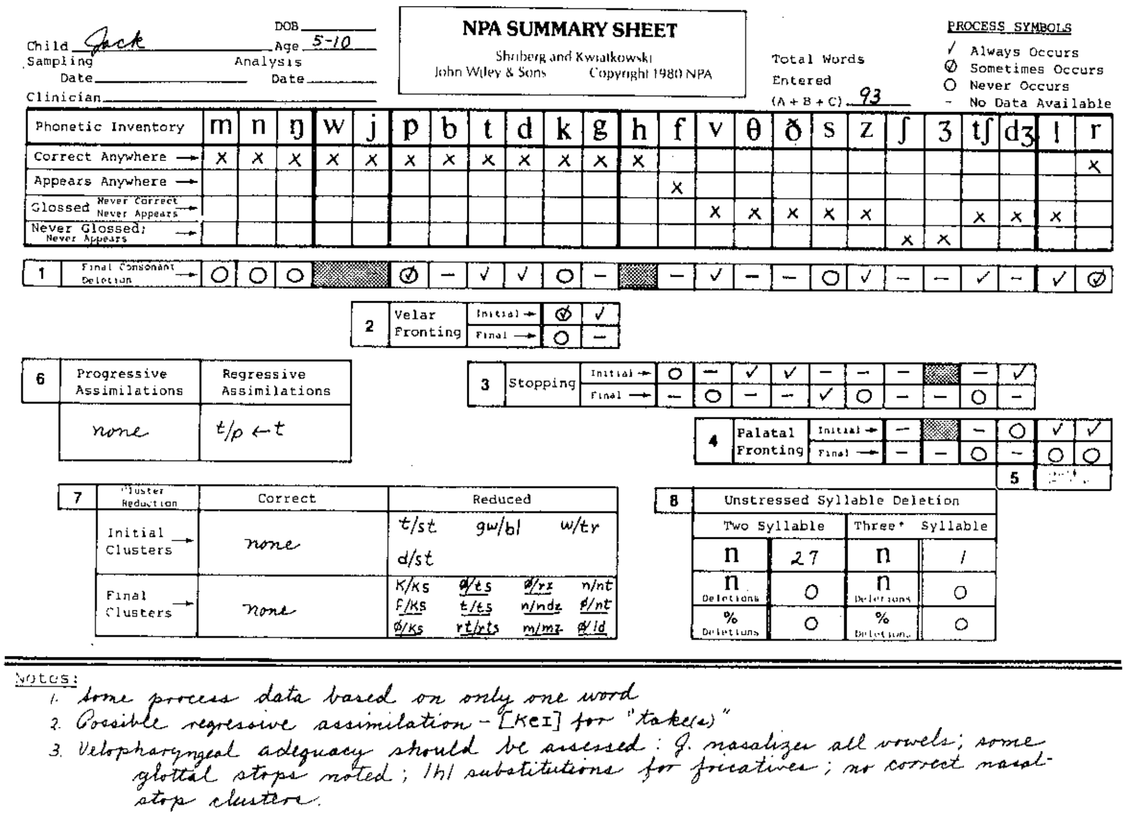
Rationale and data for selecting words to be coded for NPA are presented by Shriberg and Kwiatkowski (1980). A methodological question that had to be addressed was whether to use some arbitrary number of intelligible words in the continuous speech sample (tokens) or to use an arbitrary number of different, first occurrence words (types). Several pilot analyses done both ways and data from Templin (1957) indicated that the percentages each procedure yields for parts of speech and for morpheme structures were essentially similar. In practice, transcription and unassisted coding of an arbitrary number of sequential tokens are easier and faster, but the data could be less generalizable. As just discussed, token procedures can be biased by repetitions of lexical items that occur frequently in a particular sample. Primarily for this reason, the decision was to use only the first occurrence of a word type for the formal portion of NPA, with subsequent tokens available for informal inspection and variability analyses.

The decision to use approximately 90 word types had direct consequences for the level of measurement selected for NPA data. Because the available number of words for each speech sound X natural process was limited, a four category, ordinal level of measurement was selected to describe NPA data. That is, rather than reporting percentage data for each sound X natural process, we elected to be conservative and use the ordinal categories, "Always Occurs," "Sometimes Occurs," "Never Occurs," and "No Data Available."

When computer-assisted NPA became available in 1982, we initiated several studies to reevaluate the consequences of type versus token scoring. Computer-assisted NPA can be instructed to use either types or tokens. Moreover, in addition to the ordinal categories, such as "Always Occurs," the program computes and prints out percentages for each speech sound X natural process. Figures 3 and 4, respectively, are sample NPA summary sheets for the unassisted NPA and as output from the computer-assisted NPA. Note that the computer-assisted summary sheets include both nominal coding (asterisks for one of the four categories) and percentage of occurrence data.

Method

To assess the effects of type versus token coding on NPA, records were randomly selected from two data bases: a sample of 72 3- to 6-year-old children with normally developing speech, and a sample of 38 3- to 9-year-old children referred for delayed speech acquisition of unknown-origin. From these samples, 30 children were randomly selected from the normative group and 22 were randomly selected from the delayed speech group. All speech samples had been obtained and processed following the sampling and recording techniques in Shriberg and Kwiatkowski (1980), the transcription procedures in Shriberg and Kent (1982), and the computer entry procedures in Shriberg (1982a). Essentially, continuous speech samples were entered for analysis using a "90-70-225" rule:


NPA SUMMARY SHEET
Shriberg and Kwiatkowski
John Wiley & Sons Copyright 1980 NPA

Child Jack DOB ____ Age 5-10
Sampling Date ____ Analysis Date ____
Clinician ____
Total Words Entered (A + B + C) 93

PROCESS SYMBOLS
✓ Always Occurs
⊘ Sometimes Occurs
O Never Occurs
– No Data Available

Phonetic Inventory	m	n	ŋ	w	j	p	b	t	d	k	g	h	f	v	θ	ð	s	z	ʃ	ʒ	tʃ	dʒ	l	r
Correct Anywhere →	x	x	x	x	x	x	x	x	x	x	x	x												x
Appears Anywhere →													x											
Glossed Never Correct Never Appears →														x	x	x	x	x			x	x	x	
Never Glossed; Never Appears →																			x	x				
1 Final Consonant Deletion →	O	O	O			⊘	–	✓	✓	O	–		–	✓	–	–	O	✓	–	–	✓	–	✓	⊘

2 Velar Fronting: Initial → ⊘ ✓; Final → O –

3 Stopping: Initial → O – ✓ ✓ – – – – ✓; Final → – O – – ✓ O – – O –

4 Palatal Fronting: Initial → – – O ✓ ✓; Final → – – O – O O

5

6 Progressive Assimilations: none
Regressive Assimilations: t/p ← t

7 Cluster Reduction	Correct	Reduced
Initial Clusters →	none	t/st gw/bl w/tr d/st
Final Clusters →	none	K/ks F/ks ∅/ks ∅/ts t/ts rt/rts ∅/rz n/ndz m/mz n/nt ∅/nt ∅/ld

8 Unstressed Syllable Deletion	Two Syllable		Three+ Syllable	
	n	27	n	/
	n Deletions	0	n Deletions	0
	% Deletions	0	% Deletions	0

Notes:
1. Some process data based on only one word
2. Possible regressive assimilation – [keɪ] for "take(s)"
3. Velopharyngeal adequacy should be assessed: J. nasalizes all vowels; some glottal stops noted; /h/ substitutions for fricatives; no correct nasal-stop clusters.

Figure 3. Sample NPA summary sheet from unassisted NPA.

continuous utterances were entered until the child had uttered 90 intelligible word types or 70 partially intelligible utterances or 225 intelligible word tokens.

Results

Comparison of the effects of type versus token coding on NPA data may be summarized as follows.

DOES TYPE VERSUS TOKEN CODING AFFECT THE PHONETIC INVENTORY DATA? Table 3 is the summary of the type and token sampling data as it affects statements about a child's phonetic inventory. The two methods of sampling yielded essentially similar statements about a child's phonetic inventory. Among the normally speaking children, differences in phonetic inventory assignment occurred for only three children and on three different sounds [v, tʃ, ʃ]. Among the delayed speech children, differences occurred for seven children; of the consonant sounds affected [ʃ, s, l, v, z, dʒ, ʒ, θ, ð], the number involved for

TABLE 3. Differences in the Phonetic Inventory Section of the NPA Summary Sheet when Tabulations from Continuous Speech Samples Include only the First Occurrence of a Word (Type) Versus all Occurrences of the Word (Token)*

Subject Group	Phonetic Inventory Assignments					
			Similar		Different	
	n	*Total*[†]	*n*	*%*	*n*	*%*
Normally speaking children	36	864	861	99.6	3	0.3
Delayed-speech children	22	528	517	97.9	11	2
	58	1392	1378	98.9	14	1.0

* The four possible categorical assignments are illustrated in Figure 3.
[†] Number of subjects × 24 consonant assignments.

NPA SUMMARY ANALYSIS: First Occurrence Words

AUG 2, '83

Child AGUND-C1	Sampling Date 6-22-83
Study Identification DCS38	Sampling Clinician SB
DOB 4-17-78	Transcription Date 6-27-83
Age at Sampling Date 5.2	Transcriber SB/JK

Phonetic Inventory	m	n	ŋ	w	j	p	b	t	d	k	g	h	f	v	θ	ð	s	z	ʃ	ʒ	tʃ	dʒ	l	r
Correct Anywhere	13/14 93%	29/31 94%	4/5 80%	10/10 100%	4/4 100%	13/13 100%	12/12 100%	22/27 81%	8/10 80%	14/19 74%	1/2 50%	7/8 88%	7/7 100%	1/2 50%	0/3 0%	1/10 10%	24/29 83%	20/21 95%	0/3 0%	0/0	0/2 0%	2/6 33%	2/18 11%	8/18 44%
Appears Anywhere	0	1	1	4	4	0	1	7	16	2	0	3	1	0	0	0	8	1	2	0	1	0	0	0
Glossed Never Correct / Never Appears																								
Never Glossed Never Appears																								
1 Final Consonant Deletion	0/5 0%	0/4 0%	0/1 0%			0/0	0/0	2/4 50%	0/2 0%	0/1 0%	0/0		0/2 0%	0/1 0%	0/1 0%	0/0	0/2 0%	0/12 0%	0/0	0/0	0/1 0%	0/1 0%	1/3 33%	1/5 20%

2 Velar Fronting		k	g
	Initial	0/3 0%	1/1 100%
	Final	0/1 0%	0/0

3 Stopping		f	v	θ	ð	s	z	ʃ	ʒ	tʃ	dʒ
	Initial	0/1 0%	1/1 100%	0/1 0%	7/9 78%	0/4 0%	0/1 0%	0/2 0%		0/0	1/3 33%
	Final	0/2 0%	0/1 0%	0/1 0%	0/0	0/2 0%	1/12 8%	0/0	0/0	1/1 100%	1/1 100%

4 Palatal Fronting		ʃ	ʒ	tʃ	dʒ
	Initial	2/2 100%		0/0	0/3 0%
	Final	0/0	0/0	0/1 0%	0/1 0%

5 Liquid Simplification		l	r
	Initial	1/2 50%	0/0
	Final	2/3 67%	2/5 40%

PROCESS SYMBOLS

- Always Occurs
- Sometimes Occurs
- Never Occurs
- \- No Data Available

Total Words Entered 123

AGUND-C1-Page 2

6	Progressive Assimilations	Regressive Assimilations
	8: t → s / θ	6: d / l ← k
	13: ð → ʃ / s	

8 Unstressed Syllable Deletion			
2 Syllable		3+ Syllable	
n	25	n	8
n Deletions	0	n Deletions	1
% Deletions	0	% Deletions	13

7 Cluster Reduction	Correct and Correct~	Reduced and Uncoded
Initial Clusters	4: tr 20: dr	6: _t / st 26: tr / θr 30: __ / st 30: fw / sw 34: dw / dr 35: tʃ_ / kl 41: s_ / st 43: _t / st
Final Clusters	10: mz 12: rz 18: nt 23: fs 23: ks 30: ŋs 31: ks 41: nts 42: nd 45: ts 45: ts 47: ŋk	6: _t / nt 13: _pt / mpt 27: ʋk / rk 42: _z / rz 43: ʋnz / rnz

Notes:

Figure 4. Sample NPA summary sheets from computer-assisted NPA. The option illustrated here is "First Occurrence Words" (see text for discussion).

TABLE 4. NPA Coding Differences when Based on Word Types Versus Word Tokens*

Natural Processes	*Number of Coding Differences by Group*		*Type of Coding Differences*†	*Sounds Involved*‡	*Coding Difference Summary*		
	*NS**	*DS*			*No. Comparisons*	*No. Differences*	*% Differences*
Final Consonant Deletion	14	11	ND → N(1)	v(1)	1218	25	2.1
			N → S(20)	t(4), z(4), r(3) s(2), n(2), k(2) d(1), g(1)			
			A → S(4)	v(2), z(1), l(1)			
Velar Fronting	0	1	A → S(1)	g(1)	232	1	1
Stopping	13	14	ND → N(2)	v(2)	1102	27	2.5
			ND → S(1)	ð(1)			
			N → S(17)	ð(9), θ(2), z(2) s(2), tʃ(1), dʒ(1)			
			A → S(7)	s(2), ð(1), θ(1) f(1), z(1), ʃ(1)			
Palatal Fronting	0	1	A → S(1)	ʃ(1)	406	1	1
Liquid Simplification	3	4	N → S(3)	r(2), l(1)	232	7	3
			A → S(4)	r(2), l(2)			
Assimilation	3	3	ND → S(3)	—	116	6	5.2
			N → S(3)	—			
Cluster Reduction		4	N → S(5)	—	116	8	6.9
			A → S(3)	—			
Unstressed Syllable Deletion	0	2	N → S(2)	—	116	2	1.7
	37	40			3538	77	2.2

* Pair-wise comparisons include the 61 appropriate "boxes" for the eight natural processes on the NPA summary sheet (see Fig. 3). The 3538 comparisons result from inspecting 61 boxes for each of 58 subjects: 36 normally speaking (NS) = and 22 delayed speech (DS) subjects.

† Differences are from word type coding (left side of arrow) to word token coding (right side of arrow). The categories represented by the letters are: A: Always Occurs; S: Sometimes Occurs; N: Never Occurs; ND: No data available. The number following each type of coding difference is the frequency each type occurred.

‡ The number following each sound is the frequency the sound was involved in the coding change to the left.

each child ranged from one to three. Six of the nine consonant sounds involved are the least frequently occurring consonants in continuous speech for both normal and delayed speech children, as shown in Table 2. These few differences in type versus token coding, as might be expected, were from categories of "Never Glossed" or "Glossed But Never Correct" in the type coding to "Appears Anywhere" or "Correct Anywhere" in the token sampling (see Figs. 3 and 4).

DOES TYPE VERSUS TOKEN CODING AFFECT THE *NPA* SUMMARY SHEET DATA? Table 4 summarizes the type versus token comparisons for 24 consonants coded on the eight natural processes (see Figs. 3 and 4). Overall, type versus token coding has little effect on the results of four category coding, even at the level of individual sound X process comparisons. Across the eight processes for the two samples of children, differences ranged from less than 1 percent (Velar Fronting, Palatal Fronting)

TABLE 5. NPA Percentage of Occurrence Data Based on Types Versus Tokens*

	Word-Initial				*Word-Final*			
	Type		*Token*		*Type*		*Token*	
Variables	$\bar{X}$	*SD*	$\bar{X}$	*SD*	$\bar{X}$	*SD*	$\bar{X}$	*SD*
Singletons								
Correct	75.2	10.6	77.9	11.6	69.0	13.6	69.6	13.2
Distorted	7.3	4.0	5.2	2.5	10.1	8.4	10.3	8.0
Uncoded	2.2	2.6	2.6	3.6	2.2	2.9	2.6	2.8
Clusters								
Correct	50.5	27.0	52.7	30.3	22.2	23.3	19.7	21.3
Distorted	19.0	22.5	17.1	23.9	64.1	27.3	66.1	28.0
Uncoded	1.6	6.2	.9	3.4	20.1	5.2	29.1	7.3
Natural Processes								
Stopping	11.3	16.3	11.5	15.7	6.2	22.8	6.6	23.3
Cluster Reduction	28.8	22.5	29.5	26.6	0.9	4.3	0.5	2.1
Liquid Simplification	23.0	21.4	22.8	20.7	5.4	2.7	7.8	4.2
Palatal Fronting	20.0	36.8	16.9	35.1	32.0	27.8	30.7	24.1
Final Consonant Deletion					10.9	11.0	10.3	11.1
Velar Fronting	5.0	24.4	4.9	21.3	29.7	26.5	33.4	28.0
Assimilation	.6	1.1	0.4	0.6	0.3	0.8	0.4	0.8
Unstressed Syllable Deletion								
Two syllable words	10.4	19.1	11.5	24.1				
Three or more syllable words	11.5	6.5	11.5	6.5				

* Percentages are based on computer-assisted NPA's for 22 speech-delayed children.

to less than 7 percent (Cluster Reduction). Most of the categories in the token data changes reflected a convergence on the category "Sometimes Occurs." Summed over all 3538 pairwise comparisons, 97.8 percent of coding assignments made by type versus token coding were identical.

Table 5 is a summary of data on type versus token coding for the comparison of 22 speech-delayed children. Summary variables (that is, natural process occurrence summarized across sounds) for this comparison are taken from an analysis option available in the software package. Once again, these data reflect similar percentages of occurrence, whether calculated on only the first occurrence of a word or on all of the words in a continuous speech sample. Both the mean and the standard deviation values are generally within a few percentage points of each other in type versus token coding.

The results of these several analyses appear to support the original decision to use only the first occurrence of a word in a sample. Recently, D. Ingram (personal communication) has come to the same conclusion while reworking his phonologic analysis procedures. We prefer to retain first occurrence coding for unassisted NPA or, as discussed earlier, for occasions when a sample may be biased by repeated tokens of certain words. For computer-assisted NPA in all other situations, we now use the "All Occurrences" option, and find it useful and defensible for reporting percentage data for all sound changes. As underscored in the next section, these "numbers" are only end products of a series of conceptual and technical decisions about sound change phenomena.

COMPUTERS

How Should Computer Programs for Phonetic and Phonologic Analyses Be Evaluated?

Although institutions and researchers have long used mainframe computers to store, process, and retrieve data, the recent availability of relatively inexpensive microcomputers offers powerful information processing to a wide range of potential users. In communicative disorders, microcomputer applications for assessment and management are being introduced at a rapidly accelerating pace. Because computerized information processing is only an electronic tool, claims made for the value of any software program must be inspected as critically as that accorded paper and pencil instruments. That is, although computers can be programmed to process data easily and quickly, the merit of the product should not be judged solely on such superficial aspects as ease of use or the sheer amount of quantitative detail in the output. Rather, software programs for assessment and management should be judged on the same reliability and validity standards that apply to unassisted approaches. Importantly, the computer programmer must deal unequivocally with both conceptual and procedural detail, detail that often may be overlooked in paper and pencil methodologies. In our view, then, what requires critical evaluation in programs for phonetic and phonologic analyses are the algorithms by which a software program computes. Space permits discussion of just one relevant concern.

IS NARROW PHONETIC TRANSCRIPTION NEEDED FOR COMPUTERIZED NATURAL PROCESS ANALYSES?

Suggestions for symbols and conventions for their use were provided by Shriberg and Kwiatkowski (1980) for the purposes of narrow phonetic transcription. Given that only sound deletions and substitutions qualify as natural processes, one might ask why narrow phonetic transcription is necessary. All of the recent computer-assisted procedures of which we are aware use only broad phonemic symbols. Our experience is that for the purposes of describing a child's phonetic inventory and for understanding the uncoded sound changes that are basic to NPA methodology, some level of narrow phonetic transcription is necessary.

Perhaps the main reason why diacritic symbols and conventions for their use are needed in phonetic and phonologic analyses is that reliable coding *requires* an explicit transcription system. Consider the following example that, in fact, had to be worked out for NPA computer-assisted analyses.

As a speech-delayed child begins to say fricatives, there often is a transitional period when both the previous stop substitution (for example, [t]) plus some fricative (for example, [s]) are said. How should such behavior be transcribed by all users of a computer-assisted program for phonetic and phonologic analyses? If a child's intended /ʃ/, for example, is transcribed as [ᵗs], this sound change will be coded by the NPA program as an instance of Palatal Fronting, that is, /ʃ/ → [ᵗs]. However, if the sound change is transcribed as [tˢ], it will be coded as Stopping, that is, /ʃ/ → [tˢ]. Finally, if this speech behavior is transcribed as [t͡s], it will meet neither the Palatal Fronting nor the Stopping criteria and it will be coded as Uncoded (that is, some type of affricate). Rationale for such coding decisions is, of course, debatable; extended discussions are presented in Shriberg, 1982a; Shriberg and Kent, 1982; Shriberg et al., in press.

The point here is that computer-assisted analysis procedures require conventions for transcribing and entering into the computer the phonetic behaviors that occur in children during assessment and throughout all phases of management. One can argue that phonetic transcription is at the very heart of all phonetic and phonologic analysis procedures. Recent availability of computer-assisted programs may shift the focus away from this "front end" aspect of speech sample analysis, but the tedious and fundamental business of phonetic transcription must be carefully considered if phonetic and phonologic analyses of transcripts are to be valid and reliable. Particularly, as microcomputer procedures for prosodic analysis become available, attention to speech-signal concerns in combined phonetic-phonologic-prosodic analyses will require considerable methodological rigor.

To conclude, in the emerging technology of computer-assisted assessment and management, procedures for speech analyses will become at once more accessible and more complex. Computer software has the virtues of saving clerical time, of enabling fine-grained cross tabulations of information, and of providing for storage and instant retrieval of data that might otherwise be lost. Yet the complexity of writing software that will be both general enough to house clinical findings and theoretically specific enough to output defensible numbers poses a technical and ethical challenge to those who would undertake program development. The numbers and labels assigned children on the basis of computer-assisted output will be only as valid and reliable as the research findings that motivated the software.

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ARTICLE SEVEN

SELF-ASSESSMENT QUESTIONS

1. The primary purpose of both the unassisted and computer-assisted NPA is to:
   (a) describe sound changes
   (b) identify both natural and "uncoded" sound changes
   (c) identify natural sound changes and explain their origins
   (d) determine the percent occurrence of each of the natural phonological processes
2. "Uncoded" sound changes in speech-delayed children:
   (a) are of no interest in phonetic and phonologic analyses
   (b) occur only in multisyllabic words
   (c) may have diagnostic value
   (d) are similar among all children with delayed speech
3. Data reported on continuous speech samples suggest that:
   (a) structurally representative speech samples can be obtained using several sampling procedures
   (b) intelligibility is lowered when the examiner asks questions
   (c) the occurrence of natural processes differs significantly across a variety of sampling conditions
   (d) single word or imitation tasks are preferred for children with delayed speech

4. On the issue of type versus token data:
   (a) token data are preferred in all cases because they increase sample size
   (b) type data are preferred in some cases, especially when samples may be biased by repeated use of certain lexical items
   (c) type data are preferred in all cases because they assure more structurally representative samples
   (d) type data should never be used for phonologic analysis

5. Of primary concern when selecting computer software for speech analysis is:
   (a) the amount of data generated by the program
   (b) ease of use of the program
   (c) whether the program includes both phonetic and phonologic analyses
   (d) the reliability and validity of the data generated by the program