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Developmental Phonological Disorders III: Long-Term Speech-Sound Normalization

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Prior articles in this series provide a descriptive profile of 178 children with developmental phonological disorders (Shriberg & Kwiatkowski, 1994) and predictive correlates of short-term speech-sound normalization in 54 children (Shriberg, Kwiatkowski, & Gruber, 1994). The present article reports findings from a study of 10 children with developmental phonological disorders whose progress was followed at least once yearly for 7 years. Analyses characterize the sequence, rates, and error patterns of long-term speech-sound normalization in relation to developmental perspectives on the nature of children's phonological disorders. Findings are interpreted to support the hypothesis of a critical period for speech-sound development, with long-term normalization of significant speech delay reaching a chronological age boundary at approximately 8.5 years.

KEY WORDS: phonology, disorders, prosody, development, prediction

Speech-sound normalization in developmental phonological disorders has been defined as the behaviors and processes by which speech becomes normally articulate over time (Shriberg et al., 1994). Two periods for the achievement of speech-sound normalization with or without intervention have been proposed: *short-term* normalization, in which normally articulate speech is achieved by 6 years of age, and *long-term* normalization, in which normally articulate speech is achieved anytime after 6 years. Short-term and long-term speech-sound normalization are assumed to involve both similar and unique linguistic processes, with long-term normalization associated with additional academic and psychosocial correlates and consequences. That is, children whose speech errors persist after 6 years of age are likely to differ in theoretically and clinically important ways from children whose speech errors have normalized by 6 years. A prior article in this series addressed prediction issues in the short-term speech-sound normalization of a group of 54 children with developmental phonological disorders (Shriberg et al., 1994). The purpose of the present paper is to consider in some detail the long-term speech-sound normalization profiles of 10 children with significant developmental phonological disorders whose progress was followed for 7 years.

Research in Long-Term Speech-Sound Normalization

The following review is organized to provide information about the *sequence, rate,* and *error patterns* observed in normal speech acquisition and in normalization of delayed speech. Specifically, (a) Do children follow a similar sequence in acquiring the sounds of their language, and, if so, does this sequence also characterize the long-term normalization of a developmental phonological disorder? (b) Do the rates of normalization for children with speech disorders parallel the rates of normal speech-

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sound acquisition, albeit several years later? and (c) Do the error patterns of children with speech disorders match the error patterns observed within the notably brief period in which most children acquire articulate speech without difficulty?

The Sequence of Speech-Sound Normalization

The concept of a developmental speech disorder is predicated on the assumption that there is a normal sequence that children follow as they acquire the consonants and vowels-diphthongs of their ambient language. This assumption follows from the observation that, within each language, children produce some sounds earlier than others and that sounds observed to be acquired early occur with greater frequency in the phonetic inventories of the world's languages. Correspondingly, those sounds observed to be acquired late occur with lower frequency in the world's languages (Jakobson, 1941/1968; Locke, 1983; Slobin, 1977). From these observations, phonological acquisition sequences are claimed to reflect outcomes of a variety of mechanisms such as *perceptual development* (Winitz, 1969, 1975), *ease of articulation* (Locke, 1983, p. 185), or the less ontologically committed *markedness* (Trubetzkoy, 1958/1969; cf., Chomsky & Halle, 1968). Information on the sequence of speech-sound mastery in normal and disordered phonology is found within each of the three major methodological periods in child language study described most recently by Ingram (1989): the period of diary studies (1876–1926), the period of large sample studies (1926–1957), and the period of longitudinal studies (1957–present).

Diary studies. Diary studies describing the sequence of both normal phonological development (e.g., Albright & Albright, 1956; Bateman, 1916; Chamberlain & Chamberlain, 1904, 1905; Grégoire, 1937; Hills, 1914; Holmes, 1927; Humphreys, 1880; Jegi, 1901; Leopold, 1947; Lewis, 1936, 1951; Menn, 1971; Moskowitz, 1970; Nice, 1917; Pollock, 1878; Smith, 1973; Velten, 1943; Weir, 1962) and disordered phonological development (e.g., Applegate, 1961; Cross, 1950; Edwards & Bernhardt, 1973; Haas, 1963; Hinckley, 1915; Lorentz, 1974) are characterized by major differences in methodologies and theoretical investments. Reviews by Edwards and Shriberg (1983), Ferguson (1973), and Ingram (1989) emphasize the rich diversity and individual variability found in the order of speech-sound acquisition, which are typically described from a system-internal developmental perspective rather than against an adult standard. It is not surprising that a primary conclusion gleaned from the information in these studies is that phonological development in children is internally consistent, but externally variable (Ingram, 1989). For example, in an examination of the acquisition sequences of fricatives and affricates implied by Jakobson's (1941/1968) *laws of irreversible solidarity*, considerable variability from the predicted universal sequence was observed across children (Ferguson, 1973; Ingram, 1989).

Cross-sectional studies. The large-scale cross-sectional studies constituting Ingram's second period of language studies include those providing age-of-acquisition data (e.g., Arlt & Goodban, 1976; Bricker, 1967; Olmsted, 1971; Poole, 1934; Prather, Hedrick, & Kern, 1975; Smit, Hand, Freilinger, Bernthal, & Bird, 1990; Templin, 1957; and Wellman, Case, Mengert, & Bradbury, 1931; cf. reviews by Bernthal & Bankson, 1993; Edwards & Shriberg, 1983; Ingram, 1989; Sander, 1972; and Smit, 1986). The normative studies are based on judgments of correct/incorrect phonological realization according to an adult standard, with considerable variation among studies as to how this adult standard is defined, applied, and reported. For these and other reasons, studies within this period are not directly comparable, nor do they yield a consistent phonological acquisition sequence.

There is ample evidence for a stable sequence of speech-sound mastery at levels superordinate to the phoneme. Menyuk (1968) constructed feature hierarchies for both normal children and children with articulation disorders, concluding that these orders represent the sequence of acquisitions and substitutions. Singh, Hayden, and Toombs (1981) conducted a cross-sectional study of 1,077 children receiving speech treatment, using a somewhat different set of features but arriving at a similar hierarchy. Since Chomsky and Halle's (1968) adoption of markedness as both a representation of the order of speech-sound acquisition and the likelihood of a sound occurring in a language inventory, it has been evident that the concept may apply to error frequency as well. For example, Toombs, Singh, and Hayden (1981) constructed a markedness matrix for seven nontraditional features of English consonant phonemes and then ranked the phonemes by the number of marked features for each. Applying their markedness metric to the articulatory substitutions of 801 children evidencing articulation disorders, they concluded there was a definite hierarchy in which more marked sounds are replaced by less marked sounds. More recently, Dinnsen, Chin, and Elbert (1992) and Dinnsen, Chin, Elbert, and Powell (1989) have proposed that feature-level processes describe the pattern of growth for phonetic inventories. Based on analyses of cross-sectional developmental literature and children's progress in speech treatment, these authors propose a five-stage developmental progression beginning with the major class distinctions [consonantal] [sonorant] [syllabic], which are required for [voice]; which in turn is required for the [continuant] [delayed release] manner distinction; which is required for [nasal]; and finally [strident] [lateral]. These levels yield a limited hierarchy of possible phonetic inventories that Dinnsen and colleagues claim characterizes both normal and delayed phonological development, whether acquired naturally or through intervention.

Longitudinal studies. The most relevant data addressing the sequence of speech-sound normalization are found in longitudinal studies, which include prospective, retrospective, and follow-up studies. The latter two designs are not usually considered appropriate for establishing normalization sequences because of the many methodological difficulties in assembling a phonological sequence from the number and types of data points available. Longitudinal studies of normal children (e.g., Dyson & Paden, 1983; Ferguson & Farwell, 1975; Hoffman, Schuckers, & Daniloff, 1980; Klein, 1985; Leonard, Mesalam, & Newhoff, 1980; Rockman, Elbert, & Saltzman, 1979; Shibamoto & Olmsted, 1978; Stoel-Gammon & Cooper, 1984; Vihman & Greenlee, 1987) have all emphasized between-subject differences. However, in the discussion of a study of 19 boys and 15 girls assessed at 3-month intervals from the age of 15 months to 2 years, Stoel-Gammon (1985) noted that the individual differences among subjects were relatively minor. Stoel-Gammon attributes this homogeneity to the age of the subjects, their stage of vocabulary acquisition, and the fact that productions were not related to an adult standard.

Among the more widely cited prospective studies describing the speech-sound normalization of speech-disordered children, reports by McDonald and Shine (1969) and by Diedrich and Bangert (1980) were concerned with a restricted number of error sounds, and a study by Weiner and Wacker (1982) provides limited phonetic data on 10 speech-delayed compared to 10 speech-normal children. Only the large-scale prospective study by Sax (1972) provides longitudinal self-correction data on the sequence of speech-sound normalization in children identified as having a speech disorder. Sax's data were based on a sample of 266 male and 269 female children who were on a waiting list for speech treatment services in a school district near Detroit. The children were tested at the beginning and end of their first school year and then yearly to the end of fourth or fifth grade. An articulation test was used in kindergarten through first grade, but in successive years responses were based on sentence imitation. The group-averaged sequence of normalization without intervention during this period was interpreted as mirroring the developmental sequence of normal speech-sound acquisition, supporting the concept of a speech *delay*.

Summary. When viewed at the level of longitudinal subject profiles, the normative studies indicate that individual speech sounds cannot each be assigned a rank-ordered position on a sequence of developmental mastery because children acquiring speech normally do not progress through an exactly similar sequence of speech-sound learning. Rather, the so-called normal sequence of speech-sound acquisition is a probabilistic ideal that is only grossly sequential at a higher-order featural level. Moreover, speech-sound acquisition does not always continue in a positive direction. A number of normative studies report reversals in mastery levels, especially for /s/ (Kenney & Prather, 1986; Poole, 1934; Prather et al., 1975; Smit et al., 1990; Templin, 1957), with Sax (1972) specifically noting the tendency of some children to adopt an error variant for /s/ and /z/ for a short time after a period of correct production. Such individual differences and inconsistencies are reflected in the typically large ranges and standard deviation values included in the tabular and graphic representations of normal speech acquisition. Lacking evidence to the contrary in the few studies of developmental phonological disorders, considerable individual differences in the sequence of each speech-disordered child's long-term speech-sound normalization are expected in the prospective 7-year study reported below.

Rate of Speech-Sound Normalization

The concept of rate of speech-sound normalization requires a measure of correctness by time, with a procedure also needed to estimate correctness values between obtained data points. Normative studies such as those cited previously have typically used a normalization criterion of 75% or 90% of children producing a sound correctly at age intervals of several months to a few years. From these data points, rate is roughly estimated by measuring the slope of the straight line between data points. Because the actual developmental function may not be linear, such assumptions can lead to considerable error in estimates of rates of speech-sound acquisition. In the most recent and comprehensive of the cross-sectional normative studies, Smit et al. (1990) do not compute rates of acquisition because growth curve modeling requires that data be collected longitudinally (cf. Wohlwill, 1973).

The most relevant methodological considerations and substantive data on rates of speech-sound acquisition were reported by Burchinal and Appelbaum (1991). These authors estimated individual developmental functions in a variety of ways for the total number of articulation errors (reported as simplification processes, cf. Stampe, 1973) recorded for 43 30- to 96-month-old children studied by Roberts, Footo, and Burchinal (1988). In the staggered longitudinal study, articulation test data were collected from each child four to six times. Five growth curve models—individual nonlinear, individual polynomial, population nonlinear, population polynomial, and prototypic—were estimated, and indices of the estimated growth curves were correlated with independent estimates of intelligibility. Results demonstrated that curve selection involves compromise between the amount of rate information gained and the ability of the curve to accurately describe a variety of sound changes. Crucial to the selection of a model was whether or not the underlying growth processes were viewed as similar or different among individual subjects—that is, whether the articulatory differences obtained were viewed alternatively as error variance or true score variance. Within the normally developing children tested with the Goldman-Fristoe Test of Articulation (Goldman & Fristoe, 1969), preschool-aged process dissolution was characterized by significant individual differences.

Summary. A number of estimation techniques for modeling developmental functions are available (e.g., McArdle & Epstein, 1987; Nesselroade & Baltes, 1979; Nunnally, 1962; Rogosa, Brandt, & Zimowski, 1982; Wohlwill, 1973). However, with the exception of the study by Burchinal and Appelbaum (1991), there are no statistical studies modeling the rates of phonological development. Bernhardt (1990, 1992) and Von Bremen (1990) suggest that, in a nonlinear phonology, higher-level features have a faster rate of acquisition and may also have precedence developmentally. These authors acknowledge that supportive data for such assumptions are as yet unavailable (cf. Bernhardt, 1992, Figure 1 for an example of a feature hierarchy in nonlinear phonology). As suggested previously, normalization rates on a variety of putative phonological units should be informative in determining whether (a) so-called speech-delayed children are, in fact, delayed only in the temporal markers for onset and normalization, or (b) their patterns of normalization provide counter evidence for the notion of simple delay (cf. Bishop & Edmundson, 1987; Locke, 1994; Wohlwill, 1973). This question will be addressed in the study to be reported.

Error Patterns in Speech-Sound Normalization

Analyses of the types of errors children make when they misarticulate speech sounds have long been central to theoretical perspectives on the nature of normal and disordered phonological acquisition. For example, Locke (1983) quotes Noble's (1888) observations that because children make the same "mispronunciations" in a wide variety of the world's languages, there must be "... some law as their inciting cause. ..." Jakobson (1941/1968) proposed his laws and principles to account not only for developmental sequence, but also for the types of replacement patterns. To date, primary descriptive information on the error patterns in speech-sound acquisition and normalization can be divided into studies based on speech sounds and those based on the constructs of phonological processes.

Speech sounds. Few normative studies of phonological development based on speech sounds also report frequencies of error types. Templin (1957) summarized the three major error types (omission, substitution, and distortion) by age level; and Snow (1963) itemized frequencies of omissions, substitutions, and moderate and severe distortions for each phoneme and provided frequencies for specific substituted phonemes. Prins (1962) and Snow and Milisen (1954) proposed an error-pattern normalization sequence from omissions to substitutions to distortions within and among sounds. This normalization sequence appears to be quite stable across children, although not all speech-error targets go through a period reflecting each error type. For example, the normalization data from five children in treatment for /s/ errors reported by Elbert and McReynolds (1978, 1979) are generally consistent with this sequence, but not all children experienced each of the three error types. As indicated in such fine-grained studies, word position interacts strongly with error type, a factor accounted for in at least some of the so-called phonological processes (e.g., Final Consonant Deletion) discussed below.

Phonological processes. Stampe (1969, 1973) and Donegan and Stampe (1979) claim that the process of speech-sound development proceeds by suppression or dissolution of certain natural processes that interfere with otherwise adult-like child phonological competence. These natural processes, which partially capture context-sensitive relationships in phonology, have been tabulated and sequenced in the speech of children with developmental phonological disorders reflecting many languages and dialects (e.g., Bortolini & Leonard, 1991; Goldstein & Iglesias, 1991; Hodson & Paden, 1981; Iglesias & Anderson, 1993; Ingram, 1974; Magnusson & Naucler, 1990; Ries, 1987; Shriberg, Kwiatkowski, Best, Hengst, & Terselic-Weber, 1986). The findings in Grunwell's (1982) study of normal process dissolution from first word use to 4 years of age have been replicated in studies by several other investigators (Dyson & Paden, 1983; Khan & Lewis, 1986; Vihman & Greenlee, 1987). In addition to the many descriptive studies, a number of studies have attempted to understand variables associated with the error patterns captured by phonological processes (e.g., Anderson & Smith, 1986; Dunn, 1982; Dunn & Davis, 1983; Paden, Novak, & Beiter, 1987; Shriberg & Smith, 1983; Smith & Stoel-Gammon, 1983). For example, reduced rates of language development and frequent deletion of final consonants have been related to early frequent use of reduplication (Fee & Ingram, 1982; Ferguson, Peizer, & Weeks, 1973; Ingram, 1989; Klein, 1981; Lahey, Flax, & Schlisselberg, 1985; Schwartz & Leonard, 1983; Schwartz, Leonard, Wilcox, & Folger, 1980). Phonological processes have been widely adopted as the analytic units for description and explanation of speech-sound acquisition and normalization; however, the many systems of process analysis have also been the source of considerable critique (cf. Bernthal & Bankson, 1993). For reasons reviewed elsewhere (Shriberg, 1991a, 1993), the study reported here uses alternative methods to describe long-term speech-sound normalization.

Summary

A fairly broad literature review indicates that, although the group-averaged sequence of speech-sound mastery appears to be essentially similar for speech-normal and speech-involved children, there are significant differences in individual sequences and error-type patterns and there are essentially no data on rates of normalization. Such findings provide only tentative support for the perspective that a developmental speech disorder actually reflects only a delay in the rate of speech-sound mastery. Rather, findings among the large number of studies of normal and disordered child phonology appear to confirm only that speech sounds differ on some multidimensional metric reflecting complexity of articulatory-acoustic features. Clearly, unlike children with nondevelopmental speech disorders, who may articulate developmentally earlier sounds less well than developmentally later sounds (e.g., difficulty with stop consonant articulation in the presence of velopharyngeal insufficiency or motor-speech deficits), children with speech disorders of currently unknown origin have difficulty with the same sounds as children acquiring speech normally. Moreover, the concept of a speech delay is not particularly informative in accounting for certain error types termed "non-natural" (Shriberg & Kwiatkowski, 1980), "unusual" (Dodd & Iacono, 1989; Leonard, 1985), or "uncommon" (Smit, 1991). A goal of the present study is to explore these and related issues by describing the long-term normalization patterns of 10 children originally referred for intelligibility problems of unknown origin.

Method

Subjects and Procedures

A longitudinal study was initiated in 1975 with 10 children (9 males, 1 female) who were referred to a preschool program at the University of Wisconsin for intelligibility problems of unknown origin. Subjects ranged in age from 3:8 to 5:4 (years:months) at first testing and from 8:11 to 11:4 at final testing. Nine subjects were seen nine times each; one male subject was tested only five times, after which his family left the city. Each child was tested at approximately 6-month

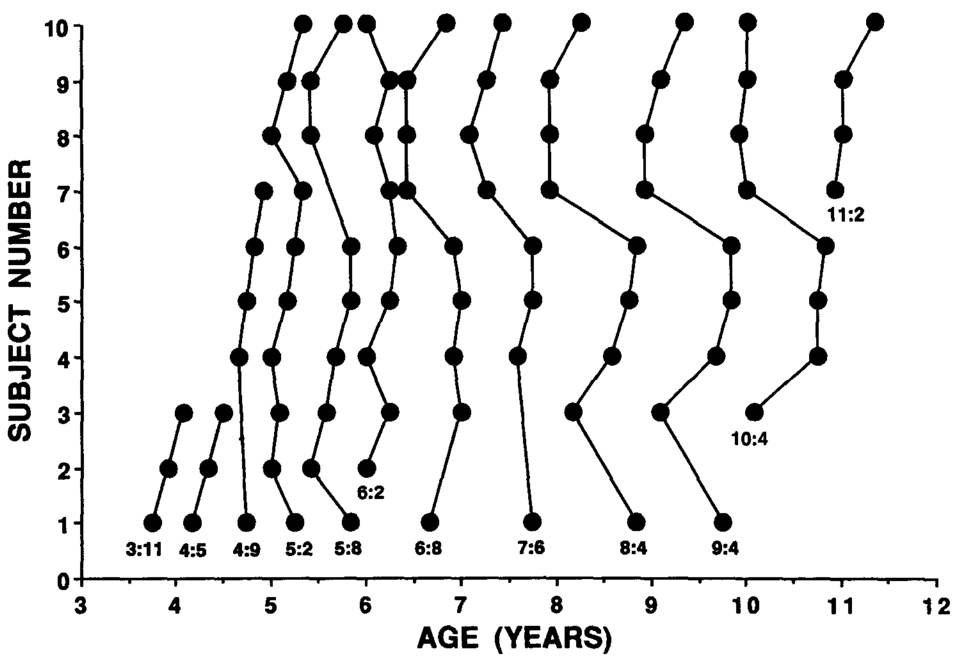

FIGURE 1. The 12 age sets derived from the ages at which each of the 10 subjects were retested during the 7-year longitudinal study. See text for grouping criteria.

intervals for five sessions and then at approximately yearly intervals for four additional sessions.

Age sets and age levels. Because testing began at different ages for the subjects, it was necessary to collapse the individual session data into arbitrary time periods termed *age sets.* The criteria used to determine subject assignment to age sets were (a) only one assessment session from each child per set, (b) a minimum of three subject assessments per set, and (c) an attempt to make sets of comparable size. Figure 1 shows the 12 age sets derived from the three criteria. Each age set (Age Set 1 through Age Set 12) included assessment data from 3 to 10 children, with 8 (67%) of the age sets including scores from 8 (80%) or more of the children. To allow for the range of subjects per age set (3–10 children) the median age in months of each age set, termed the *age level*, was used as the age reference. Thus, as shown in Figure 1, Age Set 1 was assigned age level 3:11, and so forth. The mean difference between the resulting age levels and the actual ages of subjects included in each set was 2.6 months (SD = 1.7). The maximum age discrepancy between age levels and the actual age of any one subject was 6 months, which occurred in one of the older age sets. The analyses used actual ages whenever possible and age sets/age levels elsewhere.

Procedures. The examiners for the first and second sessions were five graduate students trained to administer the procedures by one of the authors (JK). The third through final sessions for all children were conducted by the same author, who maintained communication with each child during the 7-year period of the study. Each assessment session was simultaneously audiotaped on a Nagra audiotape recorder and either an Audiotronics Model PVR-708 3/4″ B/W videotape system or a Sony AVC-3400 3/4″ B/W videotape system coupled to a JVC camera. All sessions included an administration of the Photo Articulation Test (Pendergast, Dickey, Selmar, & Soder, 1969) and a conversational speech sample. The conversational speech samples were used to obtain data on language production (Miller, 1981). The protocol completed during the first or second session included a hearing screening by staff audiologists, with some children receiving threshold audiometry and tympanometry and an oral peripheral examination. Case history data, physician records, parental reports, and school records were also assembled and coded, using procedures described in the two prior reports in this series (Shriberg & Kwiatkowski, 1994; Shriberg et al., 1994).

Subject description. Table 1 is a summary of demographic and severity of involvement information for each subject. These data were obtained from the first or second assessment session, depending on which session yielded the richest information for speech, prosody-voice, and language analyses. This sample of children had more severe phonological involvement compared to the demographically similar children with developmental phonological disorders reported in several descriptive studies (Shriberg & Kwiatkowski, 1982, 1994; Shriberg et al., 1986). As classified by the Percentage of Consonants Correct (PCC) metric, three children had *mild-moderate* speech involvement, five had *moderate-severe* involvement, and two had *severe* involvement. All subjects were, at various times, enrolled in speech treatment in the schools during the period of study, with most also receiving other special educational assistance. Their long-term normalization patterns were undoubtedly influenced by intervention, but there is no clear way to delineate specific effects from this source of variance. Because they received services differing in form and intensity during preschool and elementary years, the children in this sample are representative of children in the current educational environment.

TABLE 1. Subject description at the onset of the longitudinal study.

Subject	Gender	Age in months	Intelligibility percentage	Percentage vowels correct	Percentage consonants correct (PCC)	PCC severity level
1	M	45	60.9	80.2	42.8	Severe
2	M	47	37.5	80.3	52.2	Moderate-Severe
3	M	49	70.8	88.8	62.0	Moderate-Severe
4	F	56	69.5	88.5	49.8	Severe
5	M	57	90.5	94.1	69.2	Mild-Moderate
6	M	58	83.7	94.3	59.5	Moderate-Severe
7	M	59	51.8	87.1	74.4	Mild-Moderate
8	M	60	84.6	91.3	62.1	Moderate-Severe
9	M	62	81.3	93.0	62.0	Moderate-Severe
10	M	64	73.4	90.9	68.3	Mild-Moderate
M		55.7	70.4	88.9	60.2	
SD		6.5	16.4	5.1	9.6	

Phonetic transcription and reliability. The conversational speech samples and all sounds in the articulation tests were transcribed by a team of two experienced transcriptionists using the narrow phonetic transcription system described in Shriberg and Kent (1982) and the transcription team consensus procedures described in Shriberg, Kwiatkowski, and Hoffmann (1984). Procedures for glossing, segmenting, and formatting transcripts for computer-assisted linguistic analysis have been described in prior reports (Shriberg, 1986; Shriberg & Kwiatkowski, 1980; 1983).

Utterances from four randomly selected subjects were used to assess the reliability of phonetic transcription. A total of 78 utterances consisting of 231 words were randomly selected from the conversational samples, and a total of 74 words were randomly selected from the articulation test transcripts. Percentage of intrateam agreement was calculated by means of a computer program developed for a larger study of phonetic transcription reliability (Shriberg & Lof, 1991; Shriberg & Olson, 1988). Intrateam agreement for broad transcription of the conversational speech samples ranged from 63.6% to 100% (see Shriberg & Lof, Data Set B). Only the reliability estimates for /l/, /r/, /ʃ/, and /ð/ fell below 90%. Broad transcription reliability estimates for the articulation test data ranged from 75% to 100%. Only /tʃ/, /s/, and /f/ fell below 90%. These reliability percentages are considered acceptable for the primary data of the present study, which uses information at the level of broad phonetic transcription.

Stability of the Conversational Speech Samples

The citation-form data to be presented are spontaneous (i.e., not imitative) responses to the Photo Articulation Test (Pendergast et al., 1969) for all 86 assessment sessions. To ensure that the 86 conversational speech samples were also structurally comparable to one another and to available reference data for conversational speech samples, descriptive analyses were completed on all samples for (a) average words per utterance, (b) percentage of occurrence of each of 10 intended word forms (e.g., CVC, CV, VC targets, etc.), and (c) percentage of occurrence of each of 23 target English consonants (percentages were not calculated for the infrequent /ʒ/).

Words per utterance. The entries in Table 2 indicate the change in average words per utterance during the period of the study and comparison data for 3- to 6-year-old children acquiring speech normally (Hoffmann, 1982). Average utterance length for the first five age sets was slightly less than the average utterance lengths from samples of children acquiring speech normally. From the first to the last session, average utterance length for the children with developmental phonological disorders more than doubled.

Word forms. Data presented in Shriberg and Kwiatkowski (1983) and Shriberg et al. (1986) indicate that the percentages of intended word forms in continuous conversational speech samples are stable. The entries in Table 3 indicate the distribution of word forms per utterance during the period of the study and include comparison data for both children with delayed and with normally developing speech. The similarity of percentages and rank-ordering among sessions and between these data and comparison sources supports

TABLE 2. Average words per utterance for the 10 children during the period of study. Comparison data are from 72 3- to 6-year-old children acquiring speech normally (Hoffmann, 1982).

Age		Words per utterance		Words per utterance Hoffmann males (1982)	
Set	Level	*M*	*SD*	*M*	*SD*
1	3:11	2.4	.4	4.2	.9
2	4:5	3.1	.4	4.7	.5
3	4:9	3.3	1.0	4.0	.8
4	5:2	3.9	1.5	4.4	.7
5	5:8	4.8	.6	4.7	1.2
6	6:2	5.1	1.8		
7	6:8	5.0	1.4		
8	7:6	5.5	1.7		
9	8:4	5.2	1.3		
10	9:4	6.7	2.7		
11	10:4	7.0	2.2		
12	11:2	6.5	1.2		

TABLE 3. Distribution of intended word forms during the period of study. Comparison data are taken from the four studies of speech-normal and speech-delayed children described in Shriberg, Kwiatkowski, Best, Hengst, and Terselic-Weber (1986).

	Prior studies		Current study		Age sets																							
					1		2		3		4		5		6		7		8		9		10		11		12	
Form	R[a]	M[b]	R	M	R	M	R	M	R	M	R	M	R	M	R	M	R	M	R	M	R	M	R	M	R	M	R	M
CVC	1	30.6	1	26.8	2	25.1	1	29.0	1	35.4	1	28.6	1	27.5	1	25.8	1	25.3	1	28.4	1	25.1	1	25.2	1	23.6	1	25.2
CV	2	22.6	2	22.0	1	31.3	2	26.8	2	22.4	2	27.4	2	21.8	2	20.6	2	20.6	2	20.4	2	21.1	2	18.0	2	21.2	2	19.4
2 syllable	3	13.5	3	15.8	3	17.0	3	15.0	3	12.0	5	10.2	4	11.6	4	11.7	4	12.4	4	12.0	4	12.5	4	12.0	4	13.8	4	12.1
VC	4	12.5	4	12.3	4	11.3	4	14.3	4	11.5	3	13.7	3	17.4	3	17.0	3	15.9	3	15.2	3	16.3	3	16.6	3	18.1	3	18.8
V	5	9.0	5	8.8	5	7.8	5	7.5	5	8.8	4	11.5	5	9.4	5	9.4	5	9.7	5	8.9	5	7.6	5	7.6	5	7.3	6	6.8
C(n)VCn	6	6.1	6	5.4	6	3.6	6	2.3	6	4.2	6	4.0	6	5.4	6	5.2	6	6.7	6	5.0	6	6.6	7	6.0	6	6.0	5	7.2
CnVC	7	2.0	7	3.3	7	2.5	7	2.2	7	1.5	7	1.8	7	2.5	7	5.2	7	3.3	7	3.7	8	3.1	8	4.2	7	3.7	7	4.0
VCn	8	1.5	8	2.6	9.5	0.0	9	0.6	8	1.0	8	1.2	8	1.7	8	1.6	8	2.6	8	3.5	7	4.4	6	6.2	8	2.6	9	1.7
3+ syllable	9	1.3	9	1.1	9.5	0.0	8	1.4	9	0.3	10	0.1	9	1.2	10	0.9	9	1.2	10	0.8	9	1.2	9	2.2	9	1.8	8	1.8
CnV	10	0.9	10	0.9	8	0.5	10	0.4	10	0.2	9	0.8	10	0.8	9	1.4	10	1.0	9	1.1	10	1.0	10	1.0	10	0.6	10	1.6

[a]Rank order. [b]Mean percentage.

TABLE 4. Distribution of intended consonants during the period of study. Comparison data are taken from the four studies of speech-normal and speech-delayed children described in Shriberg, Kwiatkowski, Best, Hengst, and Terselic-Weber (1986).

	Prior studies		Current study		Age sets																							
					1		2		3		4		5		6		7		8		9		10		11		12	
Sound	R[a]	M[b]	R	M	R	M	R	M	R	M	R	M	R	M	R	M	R	M	R	M	R	M	R	M	R	M	R	M
/n/	1.0	12.0	1.0	14.3	2.0	11.1	1.5	12.0	2.0	12.8	1.0	15.9	1.0	16.0	1.0	15.2	1.0	14.7	1.0	14.9	1.0	13.9	2.0	13.4	1.0	13.7	2.0	12.8
/t/	2.0	11.8	2.0	13.2	3.0	9.9	1.5	12.0	1.0	13.5	2.0	14.4	2.0	13.7	2.0	12.8	2.0	13.4	2.0	12.9	2.0	13.5	1.0	14.9	2.0	13.0	1.0	12.8
/s/	3.0	6.9	3.0	7.7	13.0	3.6	4.0	7.2	9.0	4.5	9.0	5.2	3.0	7.8	3.0	8.9	3.0	8.9	4.0	7.4	3.0	8.5	3.0	8.3	3.0	9.2	3.0	11.0
/r/	4.0	6.8	7.0	5.7	1.0	12.1	10.0	5.0	3.0	7.5	3.0	7.4	10.0	4.3	7.0	5.1	7.0	5.3	8.0	5.3	8.0	5.0	6.0	5.5	8.0	5.3	6.5	5.8
/d/	5.0	6.1	4.0	6.6	7.0	6.5	6.0	6.7	5.0	5.9	4.5	6.0	6.0	6.3	6.0	5.4	4.0	6.4	3.0	9.0	4.0	7.0	4.0	7.1	5.0	6.0	6.5	5.8
/m/	6.0	6.0	6.0	5.8	4.0	7.2	5.0	7.0	7.0	5.2	10.0	4.7	4.0	6.7	5.0	5.5	6.0	5.9	6.0	5.7	5.0	7.0	10.0	4.5	10.0	4.8	4.0	6.2
/ð/	7.0	5.4	9.0	4.7	10.0	4.8	11.5	4.6	6.0	5.4	4.5	6.0	7.0	4.8	10.0	5.0	9.0	4.3	9.0	4.9	10.0	4.1	9.0	4.8	9.0	4.9	9.0	4.6
/k/	8.0	5.3	5.0	6.3	7.0	6.5	3.0	7.6	13.0	4.1	6.0	5.9	5.0	6.4	4.0	6.9	5.0	6.2	5.0	7.0	6.0	6.3	5.0	7.0	4.0	6.1	5.0	5.8
/l/	9.0	5.3	8.0	5.0	9.0	5.1	7.0	5.8	8.0	4.9	12.0	4.3	8.0	4.5	9.0	5.0	8.0	5.0	10.0	4.9	7.0	5.3	8.0	4.9	7.0	5.4	8.0	4.8
/w/	10.0	4.8	10.0	4.6	11.5	4.3	11.5	4.6	15.0	2.8	7.5	5.3	9.0	4.5	8.0	5.0	11.0	4.0	7.0	5.5	9.0	4.6	7.0	5.0	6.0	5.5	10.0	4.5
/z/	11.0	4.7	15.0	2.7	14.0	3.1	17.5	1.3	16.0	2.7	17.0	1.5	15.0	2.4	14.0	2.6	10.0	4.0	13.0	2.7	13.0	2.8	13.0	2.6	12.0	3.4	15.5	2.3
/h/	12.0	4.4	14.0	3.0	5.0	6.8	9.0	5.4	4.0	7.0	7.5	5.3	14.0	3.1	17.0	1.8	15.0	2.5	16.0	2.1	18.0	1.5	16.0	2.0	19.0	1.5	19.0	1.3
/b/	13.0	3.4	12.0	3.5	15.0	2.7	14.0	4.1	10.5	4.5	14.0	2.8	12.0	3.3	13.0	3.7	12.0	3.6	11.0	3.8	14.0	2.8	12.0	3.3	14.0	2.6	12.0	3.4
/g/	14.0	3.2	11.0	3.8	11.5	4.3	8.0	5.7	12.0	4.2	11.0	4.5	13.0	3.2	12.0	4.0	13.0	3.5	12.0	2.9	11.0	3.9	11.0	3.7	11.0	4.5	13.0	3.2
/p/	15.0	3.2	13.0	3.5	7.0	6.5	13.0	4.3	10.5	4.5	13.0	3.0	11.0	3.8	11.0	4.2	14.0	3.2	15.0	2.3	12.0	3.2	15.0	2.3	13.0	2.9	11.0	3.5
/f/	16.0	2.1	16.0	2.2	19.0	0.7	17.5	1.3	17.5	1.8	16.0	2.0	16.0	2.1	15.0	2.2	16.0	2.1	14.0	2.5	15.0	2.5	14.0	2.6	16.0	2.2	15.5	2.3
/j/	17.0	1.7	17.0	1.7	16.5	1.2	16.0	1.4	14.0	3.3	15.0	2.2	18.0	1.4	19.0	1.3	18.0	1.3	17.0	1.4	16.0	2.1	20.0	1.4	20.0	1.4	17.0	1.7
/ŋ/	18.0	1.6	18.0	1.5	18.0	1.0	15.0	2.2	19.0	1.4	18.0	1.2	20.0	1.2	16.0	1.8	19.5	1.2	20.5	0.7	19.0	1.5	17.0	1.7	17.0	1.9	18.0	1.6
/v/	19.0	1.5	20.0	1.1	16.5	1.2	22.0	0.3	17.5	1.8	19.0	0.8	19.0	1.2	21.0	0.7	19.5	1.2	19.0	0.8	21.0	1.0	18.5	1.7	18.0	1.6	20.0	1.2
/ʃ/	20.0	0.9	19.0	1.4	22.0	0.2	19.0	0.6	20.0	0.9	22.0	0.3	17.0	1.5	18.0	1.4	17.0	1.9	18.0	1.2	17.0	1.6	18.5	1.7	15.0	2.4	14.0	2.5
/θ/	21.0	0.9	21.0	0.7	22.0	0.2	21.0	0.4	22.5	0.4	21.0	0.5	21.0	0.7	20.0	0.7	22.0	0.5	22.0	0.7	20.0	1.1	21.0	0.6	21.5	0.6	21.0	1.1
/dʒ/	22.0	0.7	23.0	0.4	20.0	0.5	23.5	0.0	21.0	0.5	23.0	0.2	23.0	0.3	23.0	0.2	23.0	0.4	23.0	0.4	23.0	0.2	23.0	0.3	21.5	0.6	22.0	1.0
/tʃ/	23.0	0.6	22.0	0.6	22.0	0.2	20.0	0.5	22.5	0.4	20.0	0.7	22.0	0.6	22.0	0.4	21.0	0.6	20.5	0.7	22.0	0.5	22.0	0.6	23.0	0.4	23.0	0.7
/ʒ/	24.0	0.0	24.0	0.0	24.0	0.0	23.5	0.0	24.0	0.0	24.0	0.0	24.0	0.1	24.0	0.0	24.0	0.0	24.0	0.0	24.0	0.1	24.0	0.0	24.0	0.1	24.0	0.1

[a]Rank order. [b]Mean percentage.

the stability of the conversational speech samples. Specifically, although the number of words per utterance increased throughout the study (Table 2), the conversational speech samples maintained essentially similar and representative distributions of word forms.

Intended consonants. The entries in Table 4 are the distributions of intended consonants during the period of study and comparison data for children with normal and with delayed speech development. Summed over all 86 test sessions, the rank-order correlation of the percentage of intended consonants in the present data with the means for the comparison studies was .97. Discussion of factors underlying the characteristic stability of word forms and intended consonant types in conversational speech is presented in Shriberg (1982).

Results and Discussion

Findings are organized by the three-part framework used to review the literature—information on the sequence, rate, and error patterns observed in long-term speech-sound normalization. Subsections within each of these dependent variables address effects associated with alternative modes of assessment (articulation tests, conversational speech samples) and linguistic units (developmental sound classes, individual speech sounds, word position), using comparable data sets from children with normal speech acquisition and developmental phonological disorders. The goal of these analyses is to construct a detailed profile of long-term speech-sound normalization in children identified in preschool years as having a significant speech delay of unknown origin.

The Sequence of Long-Term Speech-Sound Normalization

This section begins with a description of individual differences in the sequence of speech-sound normalization for each subject. These data are followed by a series of group-level analyses of potential interactions of sequence with mode of sampling and word position. The primary question is whether the temporal sequence of speech-sound normalization in boys and girls with phonological disorders is similar to the sequence characterizing normal speech-sound acquisition.

Individual sequences of speech-sound normalization. Table 5 is a summary of the rank-ordered, speech-sound normalization data for the nine subjects who were tested nine times in 7 years (incomplete data for Subject 2 are excluded from this table). The entries in each row indicate the order of speech-sound normalization based on the earliest session in which each of the consonants normalized. The Appendix describes the criteria used to classify sounds as normalized in the articulation test data and the conversational speech samples of the present study and two comparison normative studies. Vertical lines between sounds indicate ties at those ranks (i.e., sounds that met the criteria for normalized at the same assessment session). The order of entry for all tied ranks was determined by the sequence listed for the Early-8, Middle-8, and Late-8 sounds in the speech profile format in Shriberg (1993); see Figure 2 in the present paper for the 24-consonant sequence. These rank-ordered data are proposed as the best description of the individual sequences of speech-sound normalization for each of the nine children.

Keeping in mind the approximately 6- to 12-month gaps between test sessions and the large number of tied ranks, entries in Table 5 indicate notable individual diversity in speech-sound normalization sequences. No two children had an exactly similar sequence of speech-sound normalization based on either articulation test responses or conversational speech samples. The greatest differences in sound sequences within and between children occurred for the Early-8 and Middle-8 sounds. The Late-8 sounds had greater rank-order stability across children. For all children in both sampling modes, reversals were most evident on Early-8 and Middle-8 sounds.

Spearman Rho coefficients were computed from the data in Table 5 to provide quantitative estimates of the similarity of the sequences. The interest was in the absolute magnitude (i.e., R^2) of coefficients, rather than in whether any coefficients reached levels required for statistical significance. A matrix of coefficients compared each of the nine normalization sequences in each mode with each other sequence. For the articulation test data, the 36 intersubject coefficients (i.e., each child with every other child) ranged from .44 to .83 (M = .70; SD = .09), which when squared accounts for approximately 19% to 69% of common variance in normalization sequences. For the conversational speech data, the 36 intersubject coefficients ranged from .42 to .88 (M = .67; SD = .12), which accounts for approximately 18% to 77% of common variance. The nine intrasubject coefficients (i.e., comparing each child's sequence as sampled by articulation testing versus conversational speech sampling) ranged from .54 to .90 (M = .64; SD = .12), which accounts for approximately 29% to 81% of common variance. Subsequent analysis by word position (see following section) indicated that the normalization sequence obtained by the two modes was highly correlated for sounds in word-initial position (Spearman Rho = .91) and moderately correlated in word-medial (Spearman Rho = .46) and word-final (Spearman Rho = .49) positions.

Position of sound in the word and sampling mode. Table 6 is a group-level summary of the rank-ordered sequence of speech-sound acquisition by word position and sampling mode. The procedures used to derive the individual data in Table 5 were used to derive these grouped data in Table 6, with percentages reflecting the sequence averaged across the nine children. Visual inspection of the eight sequences in Table 6 suggests that the group sequence differs considerably by position of the sound within the word and sampling mode.

Quantitative evaluation of the similarity among the eight sequences in Table 6 was estimated by the Spearman Rho coefficients summarized in Table 7, which range from .01 to .91. Once again, word position and sampling mode are associated with differences in the magnitudes (and significance levels) of the coefficients. Over all word positions (total) the correlation between sequences obtained in each sampling mode is .51. However, when computed by word

TABLE 5. Speech-sound normalization sequence for 9 of the 10 subjects tested in each sampling mode.[a]

	Articulation testing									Conversational speech								
Sub#: Rank	**1**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**1**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	h	m	b	m	n	h	m	n	m*	j	m	m	m	m*	j	w*	n*	m*
2	m	n	h	n	ŋ	m*	p	w	w*	θ*	ŋ*	j	n*	n*	b*	b	w	n
3	ŋ*	p	m	ŋ*	w	ŋ*	b	b	p	z*	j*	b*	w	w*	d*	f*	j*	w
4	n	b	p	w	t	b	h	t	b	h*	p	h	j*	b*	g*	h	b*	j*
5	w	t	j*	p	g	w	n	d	t	m	g	p	p*	d*	n*	m	d*	p*
6	p	d	t	b	m	d*	t	h	d	n	v*	w*	b*	h*	w	n	f*	b
7	b	k	f*	t	p	p	k	m	k	w	h*	tʃ*	d*	j*	f*	p	θ*	d*
8	t	g	tʃ	d	b	k	w*	p	n	p	dʒ*	dʒ*	k*	p*	h*	g	h*	g*
9	d*	ʃ	n	k	f	g	g	f	ŋ*	b	w	f	g*	ʃ*	tʃ*	ŋ	m	f*
10	k	h	w*	g	h	n	f	ð	g	v*	b*	ʃ*	f*	t*	m*	j	t*	h*
11	g	ŋ	ʃ*	f	d	j*	d	k	f*	g	k*	g	θ*	k*	p	d	tʃ*	dʒ*
12	f	w*	dʒ	ð*	k	t	ŋ	g	ð*	f	n	n	ʃ*	g*	dʒ	k	p	ʃ*
13	v	j*	d	h	j	f*	θ	v*	z*	ŋ*	d	t	h*	v	k	v*	k	tʃ*
14	θ	tʃ	ŋ*	tʃ	v	v*	ð	θ	h	t*	f*	d*	tʃ	f	θ*	θ	g	k
15	ð	dʒ	k	dʒ*	s*	ð	s*	ʃ	tʃ	d	ʃ*	v	dʒ*	ð*	v	s*	v	v
16	j	f	g	ʃ*	z*	s*	z	tʃ	dʒ	k	tʃ	k	v	θ	t#	z*	ŋ*	t
17	l#	ð	v	j	θ	dʒ*	ʃ	dʒ	ʃ	ð*	θ*	θ	ŋ*	z*	ð#	ʃ*	ʃ*	s
18	z#	v	s	s	ð	θ	tʃ	ŋ	v*	dʒ	t*	s#	t*	s*	s#	tʃ	dʒ	θ
19	r#	θ	z	v*	tʃ	ʃ	dʒ	j	j	ʃ*	s	z#	ð	tʃ	ʃ#	t*	s	z*
20	s#	s	θ	θ	ʃ	tʃ	j	s*	s	tʃ*	z	ð#	s#	r*	z#	ð*	z	ʒ
21	ʃ#	z	ð	z	dʒ	z#	v	z*	ʒ	l#	ð*	ŋ#	z#	ʒ	ŋ#	ʒ	ð#	ð#
22	ʒ#	ʒ	ʒ	ʒ	r*	l#	ʒ	ʒ	θ	r#	l#	l#	l#	dʒ	l#	dʒ	l#	l#
23	tʃ#	r*	l#	l#	ʒ	r#	l	l#	l#	s#	r#	r#	r#	l#	r#	r#	r#	r#
24	dʒ	l#	r#	r#	l#	ʒ#	r*	r#	r#	ʒ#	ʒ#	ʒ#	ʒ#	ŋ#	ʒ#	l#	ʒ#	ŋ#

[a]Vertical bar between sounds indicates tied rank-order.
*Reversals occurred after the 75% criterion for articulation testing or the 90% criterion for conversational speech was reached.
#Never reached the 75% or 90% criterion.

position the coefficients between the two sampling modes are highly correlated in word-initial position (.91) and only moderately correlated in word-medial (.46) and word-final (.49) positions. The correlation between sequences derived from the total consonants and any one word position is high for word-initial (articulation testing = .64, continuous speech = .73) and word-medial (articulation testing = .69, continuous speech = .60). The correlation between sequences derived from the total consonants and word-final position is only moderate in articulation testing (.46) and wholly uncorrelated in continuous speech sampling (.01). The latter finding is likely explained by the increased frequency, variety, and instability of speech-sound errors word-finally (Shriberg & Kwiatkowski, 1994), a thesis supported by the higher number of reversals word-finally (see later discussion).

Speech-sound normalization sequences compared to normal speech acquisition. Table 8 and Table 9 provide comparisons of overall speech-sound normalization sequences for subjects in the present study and subjects in two normative studies. Table 8 includes the rank-ordered normalization sequences (mastery level = 75% correct; see Appendix) from the 997 boys and girls in Smit et al. (1990), the 72 boys and girls described by Hoffmann (1982), and for 9 of the

TABLE 6. Speech-sound normalization sequence by word position and mode of speech sampling.[a,b]

	Initial position		Medial position		Final position		Total	
Rank	AT	CS	AT	CS	AT	CS	AT	CS
1	h	m	p*	g*	m	m*	h	m*
		|			|			|
2	m	j*	ŋ*	m*	t*	v*	m*	j*
	|	|		|	|	|	|	
3	n	p*	f*	w*	f*	θ*	ŋ*	w*
	|	|		|		|	|	|
4	w*	b	b	b*	k*	tʃ*	p*	b
	|	|					|	|
5	j	t*	m	ŋ*	n	p*	b	h
	|		|	|	|			
6	p	h	n	p*	ŋ*	n*	t	n*
	|		|		|			|
7	b	n*	t	ð*	p	g	n	d*
	|	|			|	|	|	
8	d	d*	ð*	n*	b*	dʒ	d	ʒ*
		|		|	|		|	
9	t	tʃ*	d	j	d	b	f	p
	|		|	|		|		
10	g	w*	v	ʃ*	g	k	w	g
						|	|	|
11	f	f	w	ʒ*	v	ð*	ð*	f
			|	|	|	|		|
12	k	k	j	h	θ*	ʃ*	k	v*
	|	|	|	|	|		|	|
13	v*	g	k	tʃ*	s*	t	g	ʃ*
	|	|	|		|	|	|	
14	tʃ	v	g	v*	z*	f	v	k
	|	|	|		|			
15	dʒ	ʃ*	θ	d	ʃ	s#	j	tʃ
			|		|		|	|
16	ʃ	θ*	s	f*	dʒ	z#	ʃ	dʒ
		|	|	|			|	
17	θ	dʒ*	ʃ	θ	tʃ	d#	tʃ	t
			|				|	
18	s*	ð#	tʃ	k	l#	ŋ#	dʒ	θ#
			|					
19	ð	s#	dʒ	dʒ	r#	r#	θ	s#
	|						|	
20	l	l#	z*	s	ð+	l#	s*	z#
				|			|	
21	z#	r#	ʒ	t	ʒ+	ʒ+	ʒ	ð#
22	r#	z+	l#	z#	(w)	(w)	z	ŋ#
23	(ŋ)	(ŋ)	r#	l#	(j)	(j)	l#	l#
24	(ʒ)	(ʒ)	h+	r#	(h)	(h)	r#	r#

[a]Vertical bar between sounds indicates tied rank order. [b]Articulation Testing (AT); Conversational Speech (CS).
*A reversal below the 75% or 90% criterion occurred.
#The sound never achieved criterion.
+Insufficient data to rank.
( )Does not occur in this position.

10 speech-delayed children (excluding the incomplete data from Subject 2) in the present study. Smit et al. assessed 3- to 9-year-old children in a cross-sectional design using a picture articulation test devised for the study. Hoffmann tested 3- to 6-year-old children cross-sectionally using the continuous speech samples and the Photo Articulation Test (Pendergast et al., 1969). Both normative studies used assessment procedures similar to the protocol used in the

TABLE 7. Spearman-Rho correlation coefficients (corrected for ties) corresponding to speech-sound normalization sequences by word position and mode of speech sampling.

		Initial position		Medial position		Final position		Total	
		CS	AT	CS	AT	CS	AT	CS	AT
Initial position	CS	—							
	AT	.91†	—						
Medial position	CS	.41*	.45*	—					
	AT	.42*	.30	.46*	—				
Final position	CS	.26	.14	.22	.47*	—			
	AT	.34	.25	.07	.72†	.49*	—		
Total	CS	.73†	.82†	.60†	.20	.01	.08	—	
	AT	.63†	.64†	.61†	.69†	.16	.46*	.51*	—

*$p < .05$.
†$p < .01$.

longitudinal study of the 10 speech-disordered children. Entries in Table 8 reflect responses to the two articulation tests that were scored only by target position for the Smit et al. and Hoffmann studies, but included transcription of all consonant sounds for the present study. Table 9 is a summary of Spearman Rho correlation coefficients for each relevant pairwise comparison between acquisition and normalization sequences. The information in Tables 8 and 9, which to accommodate the Smit et al. data are based only on articulation test responses, provides comparisons of normal acquisition and normalization sequences at the levels of gender and word position.

Gender. As the current study includes 9 boys and 1 girl, an initial question is whether gender is an important independent variable in generalizations about the sequence of normal speech acquisition and speech-sound normalization. Although the question cannot be posed directly within the current data set of speech-disordered children, gender information from the two normal acquisition data sets studies can at least suggest interpretative guidance.

There are seven Spearman Rho coefficients aligned diagonally in Table 9 that express the similarity in sequence of normal speech acquisition for boys and girls within the Smit et al. (1990) and the Hoffmann (1982) studies. The three coefficients for the Smit et al. data comparing the boys' acquisition sequences to the girls' acquisition sequences in word-initial (.89), word-final (.98), and overall (total) (.94) positions are strong positive. The four coefficients for the Hoffmann data, which include word-initial (.95), word-medial (.96), word-final (.83), and total (.95), are also strong positive. These coefficients suggest that the sequences of speech acquisition observed in boys and girls in two studies using different articulation tests are highly similar in all word positions. These data appear to provide the needed support for collapsing gender in all subsequent analyses of the 10 speech-disordered children.

Word position. A finding reported above was of low to moderate correlation between the speech-sound normalization sequences of 9 of the 10 speech-disordered children as assessed at the level of the position of the sound in the word.

TABLE 8. Speech-sound acquisition sequence reported by Smit et al. (1990) and Hoffmann (1982) compared to the speech-sound normalization sequence in the present study as evoked by citation form articulation testing for all three studies. For each study, ranking reflects a 75% correct criterion. The age ranges of subjects in the Smit study are from 3:0 to 9:0 years; for Hoffmann, 3:0 to 6:0 years; and, for the current study 3:9 to 11:4 years. The Smit and the Hoffmann studies were cross-sectional.[a]

	Smit et al. (1990) N = 514 males, 483 females						Hoffmann (1982) N = 36 males, 36 females								Present study N = 9 males, 1 female			
	Initial		Final		Total		Initial		Medial		Final		Total		Initial	Medial	Final	Total
Rank	M	F	M	F	M	F	M	F	M	F	M	F	M	F	Both	Both	Both	Both
1	m	m	m	m	m	m	m	m	m	m	m	m	m	m	h	p*	m*	h
2	n	n	n	n	n	n	n	n	n	n	n	n	n	n	m	ŋ*	t*	m
3	h	h	p	p	p	p	w	w	ŋ	ŋ*	ŋ	ŋ	ŋ	ŋ	n*	f*	f*	ŋ*
4	w	w	b	b	b	b	j	j	w	w	p	p	w	w	w*	b	k*	p
5	j	p	t	t	t	t	p	p	j	j	b	b	j	j	j	m	b*	b
6	p	b	d	d	d	d	b	b	p	p	t	t	p	p	p	n	n	t
7	b	t	k	k	k	k	t	t	b	b	d	d	b	b	b	t	ŋ*	n
8	t	d	g	g	g	g	d	d	t	t	k	k	t	t	d	ð*	p	d
9	d	k	f	f	f	f	k*	k	d*	d	g	g*	d	d	t	d	d	f
10	k	g	tʃ	s*	v	s*	g*	g	k*	k	f	f	k*	k	g	v	g	w
11	g	f	v	v	tʃ	v	f	f	g	g	v	v	g	g	f	w	dʒ	ð*
12	f	s*	dʒ	ʃ	dʒ	ʃ	h	θ	f	f	θ	θ	f	f	k	j	v	k
13	v	j	s*	tʃ	s*	tʃ	v	h	v	v	ð*	ð*	h	v	v*	k	θ*	g
14	dʒ	v	ʃ	r*	ʃ	dʒ	θ	v	ð*	ð	r*	l*	v	h	tʃ	g	s*	v
15	ʃ	ð	r	dʒ	r	l*	ð*	ð*	θ	θ*	tʃ#	r*	θ	θ	dʒ	θ	z*	j
16	tʃ	ʃ	θ	l*	θ	θ	l*	z*	l	z*	dʒ#	dʒ#	ð	ð*	ʃ	s	ʃ	ʃ
17	s*	tʃ	ŋ*	z*	z	z	r*	ʃ*	r#	l*	l#	z#	l#	z*	θ	ʃ	tʃ	tʃ
18	ð	dʒ	z	ŋ*	l	r	tʃ#	l	ʃ#	r	s#	ʃ#	r#	l	s*	tʃ	l#	dʒ
19	r	z	l	θ	ŋ+	ŋ+	s#	r	z#	dʒ#	z#	ʒ#	tʃ#	r	ð	dʒ	r#	θ
20	θ	θ	ð+	ð+	h+	h+	z#	tʃ#	tʃ#	ʃ#	ʃ#	tʃ#	z#	dʒ#	l	z*	ð+	s*
21	z	l	ʒ+	ʒ+	w+	w+	ʃ#	dʒ#	dʒ#	ʒ#	ʒ#	s#	ʃ#	ʃ#	z#	ʒ	ʒ+	ʒ
22	l	r	(w)	(w)	j+	j+	dʒ#	s#	s#	tʃ#	(w)	(w)	s#	ʒ#	r#	l*	(w)	z
23	(ŋ)	(ŋ)	(j)	(j)	ð+	ð+	(ŋ)	(ŋ)	ʒ#	s#	(j)	(j)	dʒ#	tʃ#	(ŋ)	r#	(j)	l#
24	(ʒ)	(ʒ)	(h)	(h)	ʒ+	ʒ+	(ʒ)	(ʒ)	h+	h+	(h)	(h)	ʒ#	s#	(ʒ)	h+	(h)	r#

[a]Vertical bar between sounds indicates tied rank-order.
*Reversals occurred after the 75% criterion was reached.
#Never reached the 75% criterion.
+Insufficient data to rank.
( )Does not occur in this position.

The coefficients in the last four rows in Table 9 assess the similarities among sequences of normal acquisition and sequences of speech-sound normalization for each of the three word positions. Independent replications are provided by the two levels of gender within the two normative studies. As shown in Table 9, the normalization sequences for the speech-disordered children are remarkably similar to those in children acquiring speech normally. Comparing the combined-gender (*Both*) sequence from the current study with those in the two normative studies respectively, coefficients are highly positive for word-initial (male = .92, .85; female = .80, .81), word-medial (Hoffmann only: male = .71; female =

TABLE 9. Spearman-Rho correlation coefficients (adjusted for ties) for the rank-order acquisition and normalization data in Table 8.

			Smit						Hoffmann								Current Study			
			Initial		Final		Total		Initial		Medial		Final		Total		Initial	Medial	Final	Total
			M	F	M	F	M	F	M	F	M	F	M	F	M	F	Both	Both	Both	Both
Smit	Initial	M	—																	
		F	.89	—																
	Final	M	.61	.63	—															
		F	.59	.64	.98	—														
	Total	M	.60	.63	.98	.96	—													
		F	.56	.69	.95	.96	.94	—												
Hoffmann	Initial	M	.90	.80	.51	.51	.49	.46	—											
		F	.82	.71	.46	.45	.44	.40	.95	—										
	Medial	M	.58	.43	.52	.52	.50	.43	.68	.65	—									
		F	.50	.37	.41	.40	.39	.32	.63	.62	.96	—								
	Final	M	.33	.34	.80	.78	.77	.71	.39	.35	.71	.68	—							
		F	.43	.26	.63	.62	.60	.53	.51	.49	.85	.83	.83	—						
	Total	M	.74	.61	.44	.44	.40	.35	.86	.81	.81	.76	.51	.65	—					
		F	.71	.54	.40	.38	.38	.30	.81	.79	.84	.81	.53	.70	.95	—				
Current	Initial	Both	.92	.80	.45	.42	.45	.41	.85	.81	.46	.39	.17	.29	.72	.68	—			
	Medial	Both	.36	.39	.55	.51	.57	.51	.36	.34	.71	.72	.74	.69	.54	.54	.32	—		
	Final	Both	.44	.49	.86	.84	.87	.84	.38	.39	.62	.55	.83	.71	.48	.47	.28	.72	—	
	Total	Both	.62	.61	.41	.37	.41	.34	.60	.55	.53	.53	.48	.43	.77	.76	.67	.69	.48	—

.72), and word-final (male = .86, .83; female = .84, .71) positions. Once again, as shown in the bottom row of Table 9, correlations among the three studies were generally lower when sampled across the total of all word positions. Because the Hoffmann (1982) normative study is closer in methodology to the current study than the Smit et al. (1990) study, the highly positive correlations provided by these pair-wise comparisons are particularly supportive of the similarity in normal speech-sound acquisition and speech-sound normalization sequences for English consonants. As calculated at the level of word position in Table 9, normal speech-sound acquisition and speech-sound normalization share as much as approximately 85% common variance word-initially, 52% word-medially, and 74% word-finally.

Comparison to representative cross-sectional studies. To examine the methodological and theoretical generality of these findings, the speech-sound normalization sequences from the present data were also compared to widely cited cross-sectional data from normally developing children and children with developmental phonological disorders.

Table 10 is a summary of normalization sequences for five widely cited, but methodologically diverse, cross-sectional studies of normal speech acquisition (cf. Hester, Godbold, Lee, & Stephens, 1984). Each of the five studies used different criteria for subject selection, data collection, transcription, scoring, analysis, and reporting (cf. Smit, 1986). Importantly, however, each study used a mastery criterion for speech-sound normalization of 75% of subjects articulating the sound correctly. Sequences are averaged across word position and gender. Arlt and Goodban (1976) used elicited imitation to secure responses; all other studies summarized in Table 10 relied primarily on spontaneous responses to articulation tests, supplemented with imitation only when necessary. Although a number of individual sound sequences appear to be similar to the sequences presented in Table 8, overall agreement among studies is high only at levels that aggregate above the level of the phoneme.

At the class level the sequences in Tables 8 and 10 are also consistent with the Early-8, Middle-8, and Late-8 developmental classes derived from cross-sectional data on children with developmental phonological disorders (cf. Shriberg, 1991b, 1993). Figure 2 compares the present normalization sequence data to findings reported in Shriberg (1993). Sixty-four 3- to 6-year-old children with speech delays (left ordinate) are compared to the present rank-ordered longitudinal data (right ordinate) summed across children and word position. Both data sets are from conversational speech samples, collected and analyzed with nearly identical procedures and personnel. There is clearly close correspondence between the percentage correct data as scaled on the left axis and the sequence of speech-sound normalization rank-ordered from 1–24 on the right axis. The Spearman Rho coefficient of .88 between sequences indicates 78% common variance. The greatest discrepancies between the sequences in the two databases were on three Middle-8 sounds, /t/, /ŋ/, and /k/.

Summary. The findings reviewed to this point indicate that normalization sequences at the level of individual sounds are characterized by considerable individual differences across children, sampling mode, and word-position. Notwithstanding the variance associated with such factors, the descriptive data and associated correlational findings support a conclusion that the group-averaged sequence of speech-sound normalization is generally similar to sequences documented in two recent and comparable studies of normal speech-sound acquisition, as well as four other widely cited studies. Characterized at the higher-order level of phonetic manner features, the sequential order of nasals, glides, stops, fricatives/affricates, and liquids is generally stable, although not invariant (see Table 5). Characterized according to the three developmental sound classes used in the speech profiles approach, which was derived from cross-sectional data on speech-disordered children, the Late-8 sound class generally retains its last-ranked position in both the normal acquisition

TABLE 10. Speech-sound normalization sequences averaged across gender and word position for five major representative cross-sectional studies that use a 75% correct criterion. The studies are those of Wellman et al. (1931) for ages 2:0–6:0, *N* = 204; Templin (1957) for ages 3:0–8:0, *N* = 480; Prather et al. (1975) for ages 2:0–4:0, *N* = 147; Arlt and Goodban (1976) for ages 3:0–5:6, *N* = 240; and Smit et al. (1990) for ages 3:0–9:0, *N* = 997. All studies used picture articulation testing except for Arlt and Goodban (1976), which used imitation techniques.

	Study				
Rank	**Wellman**	**Templin**	**Prather**	**Arlt**	**Smit**
1	m	m	m	m	m
2	n	n	n	n	n
3	w	ŋ	ŋ	ŋ	w
4	b	w	p	p	p
5	h	p	h	b	b
6	f	h	j	t	t
7	p	f	d	d	d
8	j	j	k	k	g
9	k	b	f	g	h
10	g	d	b	w	f
11	l	k	w	h	j
12	d	g	t	f	k
13	t	r	g	v	v
14	v	tʃ	s	tʃ	ʃ
15	tʃ	ʃ	l	dʒ	tʃ
16	s	s	r	s	dʒ
17	z	t	tʃ	z	s
18	r	v	ʃ	l	ð
19	dʒ	θ	dʒ	ʒ	ŋ
20	ʒ	l	ð	ʃ	l
21	ŋ+	dʒ	ʒ	θ	θ
22	ʃ+	z	v	ð	r
23	θ+	ð	θ	r	z
24	ð+	ʒ	z	j+	ʒ+

+Sound not tested or data insufficient to rank.

and normalization data. The averaged normalization sequence for the Early-8 and Middle-8 consonant sound classes is less stable in relation to the sequences observed for normal speech-sound acquisition. Thus, the exact order of speech-sound normalization in a given child with disordered speech is not expected to follow a specific sequence. Rather, the per-child sequence of speech-sound normalization presumably reflects the multidimensional effects of perceptual, articulatory, distributional, and morphophonemic properties of the speech sounds of a language in interaction with each child's individual communicative needs and intervention histories.

Ages and Rates of Long-Term Speech-Sound Normalization

The goals of the second series of analyses were to estimate ages associated with the sequence of speech-sound normalization described above and to provide information on periods of more rapid versus less rapid rates of normalization.

Ages of speech-sound normalization. Figure 3 is a plot over time of the averaged performance of the 10 speech-disordered children on five indices of speech-sound production in conversational speech: Intelligibility Index, Percentage of Vowels Correct, Percentage of Consonants Correct-Singletons, Percentage of Consonants Correct-Clusters, and the weighted average of the latter two variables—the Percentage of Consonants Correct. Beginning with the Intelligibility Index in Figure 3 (defined as the percentage of words that could be glossed by the transcribers; Shriberg, 1986), the trend at approximately 5.5 years changes from the approximately 80% intelligibility range and below to the 90% range and above for succeeding years. The Percentage of Vowels Correct, which includes all vowels, all diphthongs, and the rhotic vowels /ɝ/ and /ɚ/, does not average over 90% correct until sometime after 8 years. Trends for the Percentage of Consonants Correct-Singletons and Percentage of Consonants Correct-Clusters are generally parallel, with differences at each of the 12 age levels ranging from 3.1% to 18.8% (*M* = 10.2%; *SD* = 5.1%). Notice that the trend for the overall consonant index—the Percentage of Consonants Correct—is closest in magnitude to the trend for Percentage of Consonants Correct-Singletons, which is weighted by the more frequent occurrence of consonant singletons. Having illustrated the parallel associations among the three consonant indices, the Percentage of Consonants Correct will be used in place of the singleton and cluster indices in all further analyses.

The shapes of these consonant normalization trends in Figure 3 and, to a lesser degree, the intelligibility and the vowel normalization trends suggest that there is a leveling of the gains in normalization between 6 and 7 years, and again at approximately 8.5 years until the latest available data point. Thus, these group-level data suggest that speech-sound normalization does not proceed in a linear fashion. Rather, normalization progress appears to differ within time periods. Importantly, when assessed by the 90% mastery criterion, speech-sound normalization is not complete for some children with developmental phonological disorders by as late as 11:4, the age of the oldest child at the last assessment session. A more detailed analysis of the ages at which normalization occurs requires examination of the rates of speech-sound normalization.

Rates of speech-sound normalization. The concept of rate of speech-sound normalization requires that absolute

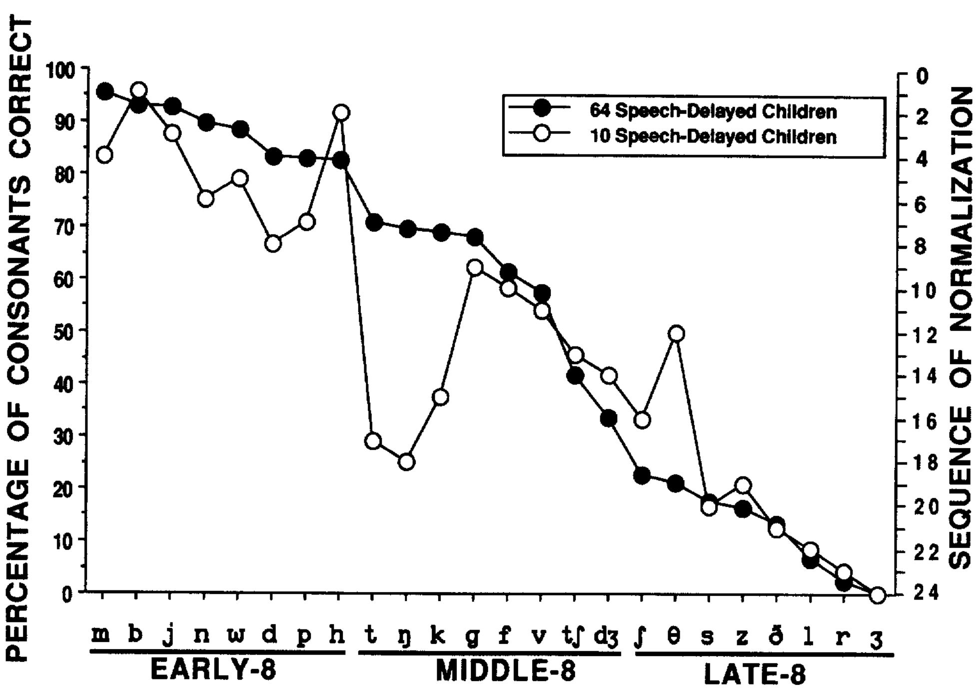

FIGURE 2. Comparison of the present longitudinal data on the sequence of long-term speech-sound normalization to the cross-sectional data for speech-disordered children reported in Shriberg (1991b, 1993).

gains in the percentage of correct sounds be converted to relative values reflecting point-to-point gains, losses, or plateaus per time period. The trends in each of the six panels in Figure 4 include such information. The three top panels provide information for the three developmental sound classes defined previously as the Early-8, Middle-8, and Late-8 sounds. The bottom three panels include rate information relative to word position—initial, medial, and final. The solid line trends in the upper portion of each of the six panels are the percentage of correct consonant sounds for each age set. The trends in the lower portion of each graph, which vacillate around the 0 percent line, reflect a measure of rate obtained as follows.

Procedure to derive rate of normalization. When the percentage of consonants correct data are plotted by age level, the line between each data point is a linear approximation of

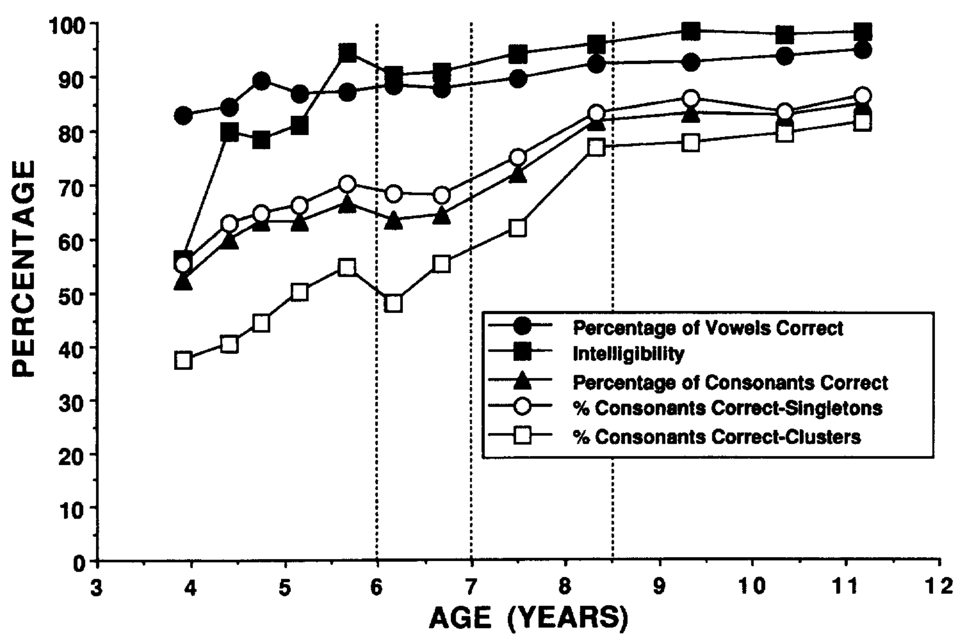

FIGURE 3. Longitudinal data for the 10 speech-disordered children on five indices of speech-sound production in conversational speech.

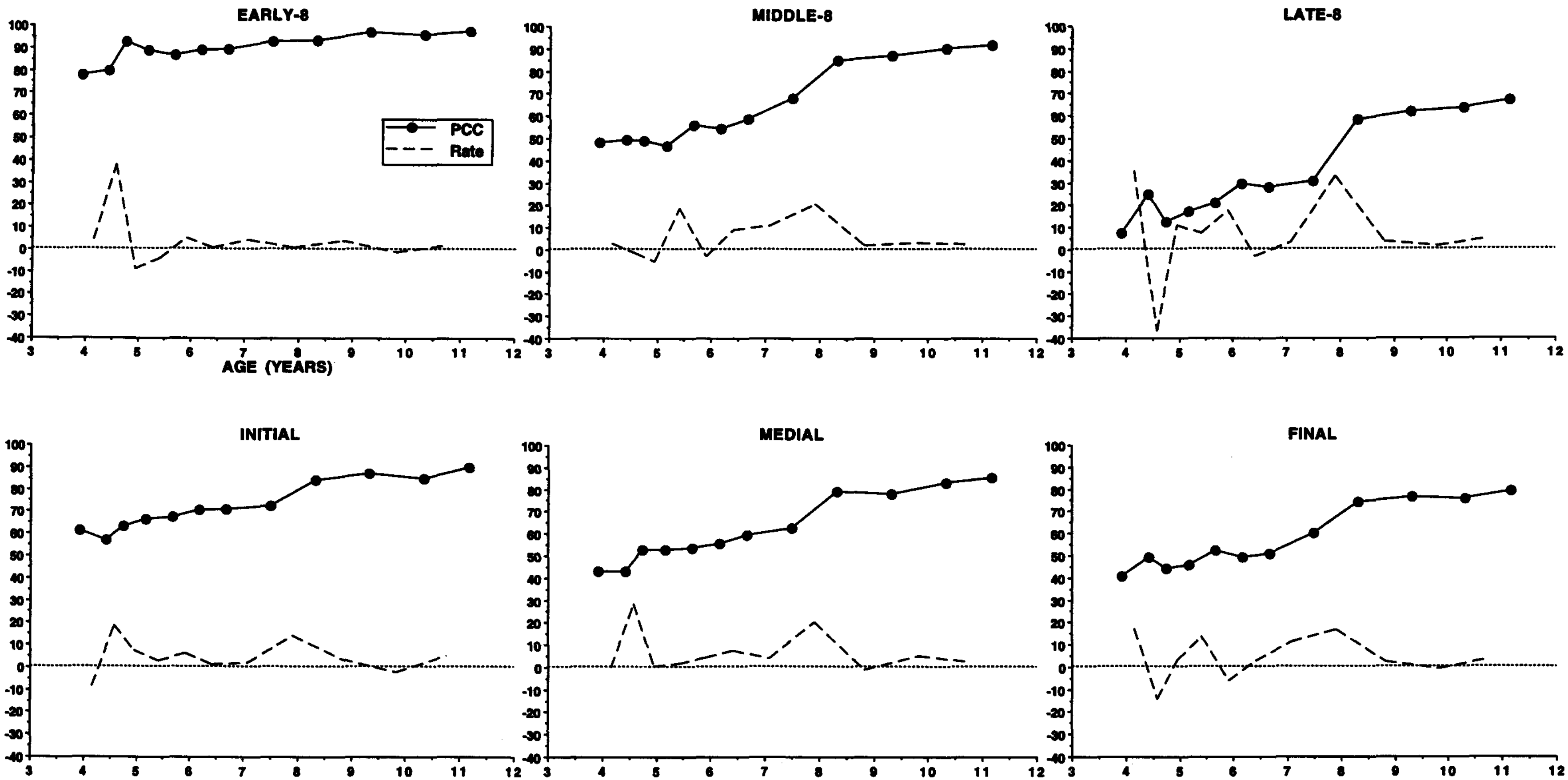

FIGURE 4. Rate of long-term speech-sound normalization displayed by developmental sound class (upper three panels) and word position (lower three panels). The upper trend is the percentage of correct consonant sounds over the period of study. The lower trend describes the rate of change in the upper trend.

a function $y = f(t)$, where y equals the cumulative normalization in percentage of consonants correct as a function f of time t. The rate of change of this function was calculated by a differencing procedure. The percentage correct value for each data point was subtracted from the value immediately following. The resulting value was divided by the age difference between the same data points. Thus, for the 12 data points representing the age sets, the differencing procedure yielded 11 data points, each representing the time-adjusted difference between two adjacent data points. The dashed trend in Figure 4 representing the *rate* of normalization (i.e., percent per year) was obtained by plotting these new data points, using the midpoint between adjacent ages to determine location on the age axis. Thus, whereas the solid line trend in each of the six panels represents the point-to-point progress towards speech-sound normalization, the dashed-line trend in each panel represents the rate of change of each line segment in the upper trend. Points above *0* on the lower trend indicate a positive rate of normalization, with peaks indicating the periods of most rapid change. Conversely, points below *0* reflect regressions in rate of normalization.

Findings: Developmental Sound Class. Beginning with the PCC trend data in the upper left panel of Figure 4, the Early-8 sounds were nearly normalized at the onset of the study with just under 80% correct, gaining approximately 20% during the study. As indicated by the Rate trend below, most of this gain occurred between ages 4:5 and 4:9, when the normalization rate peaked at an average rate of 38% per year for a brief 4-month period. After this gain, normalization proceeded at 0%–6% per year as the 100% ceiling was gradually approached.

For the Middle-8 sounds, the PCC trend indicates that approximately 50% of sounds in this class were correct at the onset of the study, with a 40% total gain achieved by approximately 11 years. Mean normalization rates are highest between ages 5:2 and 5:8 at 18% per year and from ages 6:8 to 8:4, peaking at 20% per year between ages 7:6 and 8:4. No gain or a slight regression demarcates these periods of more rapid normalization in a short 5-month period from ages 5:8 to 6:2. After about 8.5 years, progress towards normalization occurs at a rate of about 4% per year.

For the Late-8 sounds at study onset, 5% of consonants were correctly articulated. By 11 years, this improved to just under 70%, a gain of roughly 65%. The rate trend in this panel indicates a mean gain rate of 36% per year in the initial 6 months, followed by an equivalent reduction in rate reflecting the reversal in the PCC trend for the next 4 months. Because the first two data points represent the mean of only 3 of the 10 subjects (see Figure 1) these early data points may be less stable. Mean PCC gains of approximately 10%–15% occurred from 4:9 to 6:8; followed by a plateau until approximately 7.5 years. The rapid rate of normalization during the following year is indicated by the peak in rate of 32% during this period. Normalization after approximately 8.5 years proceeds at the 2%–6% rate observed for both the Early-8 and Middle-8 sounds.

These developmental sound class data provide a more fine-grained view of the index data presented in Figure 3. Specifically, they indicate that (a) for the Early-8 sounds, one brief period of normalization occurs in the latter half of the fourth year; (b) for the Middle-8 and the Late-8 sounds, two periods of more rapid speech-sound normalization occur, the first between the fifth and sixth year, and the second just before the eighth year; and (c) for all sounds not yet acquired by about 8.5 years, there is a marked reduction in further normalization rates on the order of 0%–6% per year.

Findings: Word position. The lower three panels in Figure 4 are profiles of normalization progress and rates of normalization collapsed by sound class and displayed by word position. As shown in the left-most lower panel, speech sounds in word-initial position are approximately 60% correct at 3:11 and gain about 30% over the duration of the study, with most of this gain occurring in two periods. The first period of more rapid normalization occurred from 4:5 to 4:9 at a mean rate of 18% per year. The second period from 7:6 to 8:4 had a mean gain rate of 14%. There is also a small and uncertain normalization increase in the last 10 months, possibly reflecting a small regression in the prefinal session or instability associated with the last data point, which includes data for only four subjects. Normalization of consonant sounds in word-medial position begins at approximately 42% correct at study onset, gaining approximately 40% during the period of study. Periods of greatest average rate of improvement are from 4:5 to 4:9 at 28% change per year and from 7:6 to 8:4 at 20% per year. These are approximately the same periods and similar rates found for the initial sounds. In the right-most lower panel, word-final sounds at study onset are 40% correct at 3:11 and gain an overall 40% by 11:2. There are three periods of accelerated normalization. The first, from 3:11 to 4:5 is at 18% per year; the second, from 5:2 to 5:8 reaches 14% per year; and the third period of high rate, from 6:8 to 8:4, averaged 16% per year also between 7:6 and 8:4.

These word position data provide another and compatible view of the developmental sound class data in the upper three panels. Word-initial and word-medial sounds had the highest mean normalization rates from the fourth to fifth years, whereas the peak normalization period for word-final sounds is later—at approximately 5.5 years. When collapsed across word position and weighted by frequency of occurrence, the peak normalization period occurs from 7.5 years to just over 8 years of age, the second period of more rapid normalization described above in the analysis by developmental speech-sound classes. Over the entire period of the study, average normalization rates for consonants for these children is approximately 5% per year.

Ages and rates of speech-sound normalization compared to normal speech acquisition. To compare the speech-sound normalization of the speech-delayed children with the speech acquisition of their speech-normal age mates, articulation test data were plotted for the Early-8, Middle-8, and Late-8 sounds together with the corresponding data collected by Smit et al. (1990) reported as the Iowa-Nebraska normative project. Figure 5 is a plot of the six trends reflecting percentages of consonants correct by age in years. The filled symbols are the averaged data for each sound class for the speech-delayed children in each of the 12 age sets that include from 3 to 10 children. These trends are the same as the solid-line trends in the three upper panels in Figure 4. The open symbols in Figure 5 are data average-

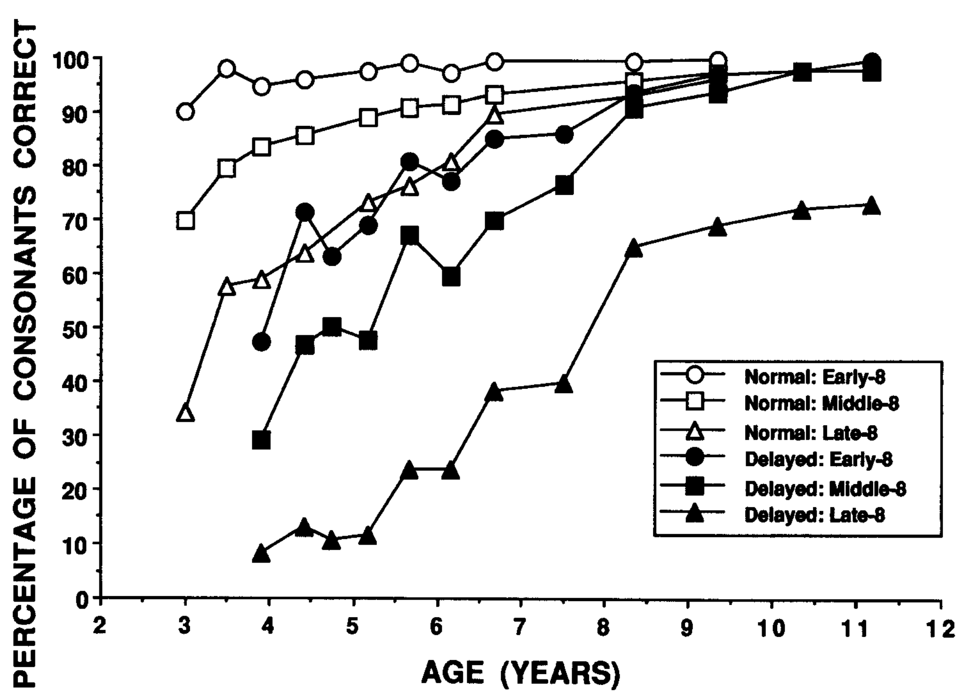

FIGURE 5. Comparison of the longitudinal normalization data for the present speech-delayed subjects with the cross-sectional acquisition data from Smit, Hand, Freilinger, Bernthal, and Bird (1990).

dacross each sound class from the cross-sectional data reported by Smit et al. using only the male data to most closely approximate the gender distribution (9 to 1) of the speech-delayed children. Each plot point in the Smit et al. data represents the responses of 22–73 children.

Focusing first on speech-sound mastery at the earliest ages reported in each study, the speech-delayed children (at 3:11) have approximately 45% of the Early-8 sounds correct, compared to 90% or twice that percentage correct for the Smit et al. (1990) study's male children (at 3:0), meeting Sander's (1972) highest criterion for speech-sound mastery. At this same age, the speech-delayed children have approximately 30% of the Middle-8 sounds correct, compared to over twice that percentage (70%) correct for the normally speaking children. For the Late-8 sounds, the relevant figures are 5% correct for the speech-delayed children and 35% for the speech-normal children, a sevenfold difference.

Under inspection in Figure 5 is how the normalization plots for speech-normal and speech-delayed children might be developmentally related, if they are. Theoretical positions outlined by Bishop and Edmundson (1987) suggest three possible alternatives: (a) speech-normal and speech-delayed children display the same course of normalization, but speech-delayed children begin to normalize later; (b) speech-normal and speech-delayed children begin normalizing at the same time, but speech-delayed children have a slower rate of normalization; or (c) speech-normal and speech-delayed children begin normalization at the same time and rate, but at some subsequent age the speech-delayed children cease normalizing. If the first of these three alternatives best characterizes the data, appropriate lagging on the age axis should result in only a single normalization course for both groups. Alternatively, if either (b) or (c) more closely characterizes the data, age-lagging should not result in a coincidence of the normalization plots.

Figure 6 includes the six normalization plots in Figure 5, lagged by the number of years and months indicated in the legend. To create the coincidence apparent in Figure 6, lagging was based on a fixed age-scale position for the Early-8 sound plot for normal children so that all adjustments were made by subtracting the appropriate years:months (see legend) from values on the age axis. A consequence of this procedure is that the resulting continuous plot in Figure 6 extends from a negative 4.5 years to a positive 10 years. The alignment needed to achieve one composite trend yields the finding that significantly speech-delayed children are approximately 5 years behind speech-normal children in acquiring the Early-8 sounds and approximately 3 years behind in acquiring the Middle-8 and Late-8 sounds.

To estimate the goodness-of-fit of the shifted normalization plots to this composite trend, age points were set to positive values and regression procedures applied (Weisberg, 1980). Figure 7 is a plot of the resulting fit for the regression equation along with unconnected plots for the age-shifted percentage of consonants correct data from Figure 6. The resulting equation accounts for a decisively high 93.3% of the variance, with a standard error of 6.83%. By traditional statistical criteria, it appears to be appropriate to claim that this equation and its corresponding fit provide a valid characterization of speech-sound normalization in both normal and speech-delayed children. The trend in Figure 7 is consistent with the position that there is a single course of normalization for both groups of children, differing only in

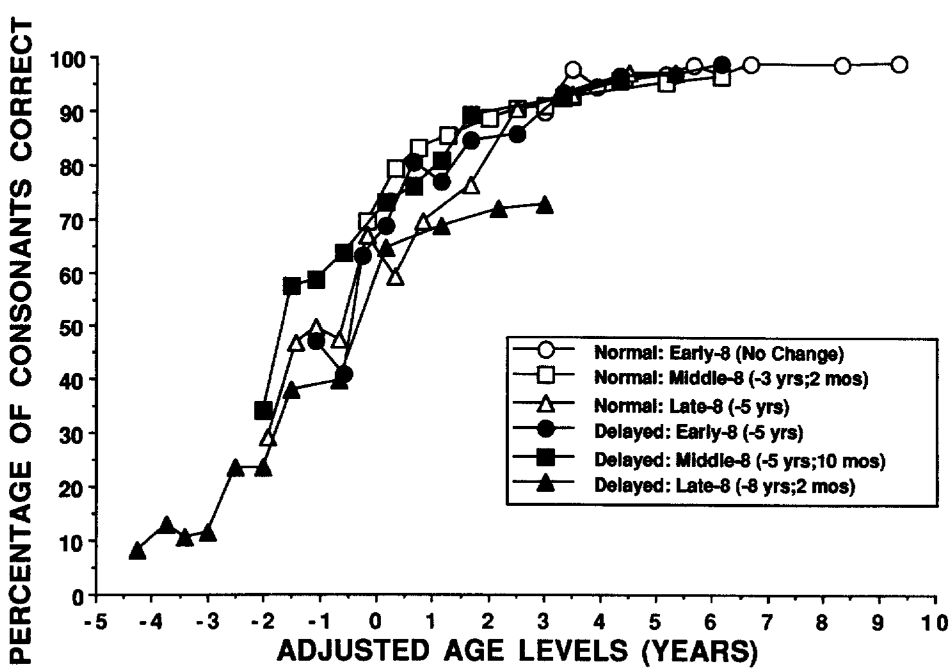

FIGURE 6. Plot of the trends in Figure 5 lagged by the number of years and months indicated in the legend.

temporal markers among the three speech-sound classes and between group assignment. This finding is markedly consistent with the first of the three hypotheses about speech-sound development proposed by Bishop and Edmundson (1987) and the findings of Curtiss, Katz, and Tallal (1992) for syntax.

An even closer fit to the normalization equation would have resulted had the normalization trend for the speech-delayed children's Late-8 sounds not flattened at about 8.5 years. Inspection of Figures 5–7 indicates that in fact little normalization occurs after 8.5 years of age for the speech-delayed children, whereas for the speech-normal children all sounds have by this time achieved a normalization ceiling. These additional findings are more consistent with Bishop and Edmundson's third hypothesis that speech-delayed children, after following the same course of speech-

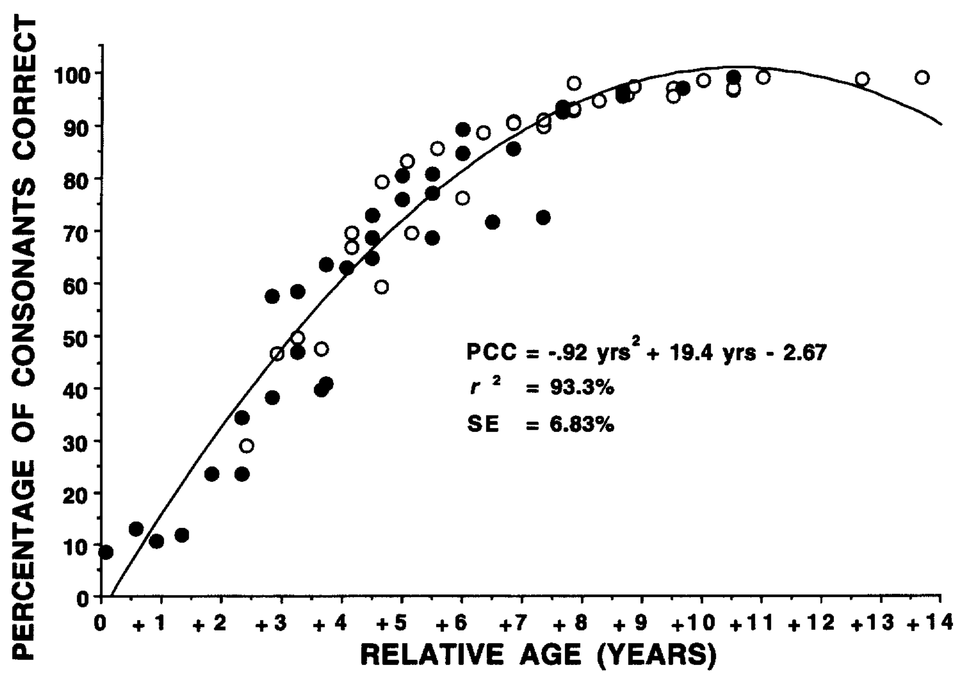

FIGURE 7. Regression analysis of the age-shifted percentage of consonants correct data in Figure 6.

sound acquisition as speech-normal children, might reach an age plateau after which little further normalization occurs. Thus, a more appropriate composite interpretation is that, in comparison with the course of normal speech acquisition, (a) speech-delayed children follow an identical, but temporally delayed, course of normalization, with the amount of delay greater for the characteristically earliest developing sounds; and (b) development is similar until about 8.5 years of age, when normalization is either essentially complete or it plateaus, leaving residual articulation errors (cf. Shriberg, 1993).

A final series of age analyses explored the validity of the second part of the above claim—that normalization plateaus at 8.5 years in speech-delayed children. Figure 8 includes normalization plots for 7 of the Late-8 sounds for the 10 speech-delayed children (there were insufficient conversational speech tokens to plot normalization of /ʒ/). The upper two panels include the cognate pairs /θ/-/ð/ and /s/-/z/, respectively; the lower panels include the trends for /ʃ/ and the trends for the liquids /r/ and /l/. For the /θ/-/ð/ cognates the most rapid period of normalization occurred from 7:6 to 8:4. After 8:4, slight gains in /ð/ are observed until 9:4. Maximal normalization rates also occur from 7:6 to 8:4 for /s/ and /z/, with both sounds continuing to improve until the last age level tested. Maximal normalization rates also occur from 7:6 to 8:4 for /ʃ/, with rather large session-to-session variability, but no appreciable gains after 8:4. Maximal rates of normalization for /l/ occur from 6:8–8:4, after which either a plateau or even a regression occurs in these group-averaged data. Finally, the pattern of /r/ normalization is difficult to characterize. From 3:11 to 8:4 normalization progress is from near zero percent correct to approximately 15% correct, after which the averaged scores range from approximately 15% correct to about 30% correct. These sound-level data support the prior overall finding of rapid growth from approximately 7:6 to 8:4, with a clear slowing of normalization after 8:4.

Error-Type Patterns in Long-Term Speech-Sound Normalization

Figure 9 includes group-level analyses of the covariance of speech-sound normalization (i.e., percentage consonants correct) with the three *absolute* error types. Thus, the four trends sum to 100% in each of the nine panels. Trends in the nine panels illustrate the interaction over time of the three primary factors in long-term speech-sound normalization: Word Position (word-initial, word-medial, word-final) × Developmental Sound Class (Early-8, Middle-8, Late-8) × Articulation Type (correct, omissions, substitutions, distortions). The distortion errors include only those classified as *clinically significant* (cf. Shriberg, 1986, 1993), the most frequent of which are dentalized sibilant fricatives, lateralized sibilant fricatives, derhotacized r-colored vowels and consonant /r/, and labialized liquids.

Early-8 sounds. Beginning with the Early-8 sounds in Figure 9, the upper three panels include for each word position the mean percentages of consonants correct and percentages of each of the error types for each age level. Omission errors are the most frequent error type for these eight early-developing sounds, becoming more frequent as the target sounds occur later in the word. Substitutions are the next most frequent error type for both word-initial and word-medial Early-8 consonants. Notice that, in word-final position, the only remaining errors after approximately 7.5–8.5 years are omissions. Distortion errors are infrequent in all word positions for the Early-8 sounds.

Middle-8 sounds. The pattern of errors for the Middle-8 sounds across word position also consisted of omission and substitution errors, with 0% or very low percent distortion errors over time. Omission errors are relatively frequent only up to approximately 5 years of age in word-initial position, up to just over 8 years in word-medial position, and up to approximately 9 years in word-final position. Substitution errors are overall the most frequent error-type for Middle-8 sounds. Particularly notable is the crossover in the frequency of omission and substitution errors at just over 5 years of age for Middle-8 sounds occurring in word-final position.

Late-8 sounds. Error-type patterns for the Late-8 sounds are generally similar in each of the three word positions. Substitution errors are most frequent in word-initial position until a sharp increase in correct sound production at about 7.5 to just over 8 years, after which distortion errors are most frequent. In word-medial position, all three error types occur with roughly equal frequency until approximately 7.5 years, after which distortion errors also become most frequent. Finally, in word-final position, the three error types occur with approximately equal frequencies until the sharp increase in correct production of Late-8 sounds at just over 8 years, after which distortion errors are most frequent. Thus, as Late-8 sounds reach their overall levels of approximately 60%–70% correct in each of the three word-positions at just over 8 years, the absolute error types also stabilize at approximately 25%–30% distortions, 10%–15% substitutions, and 0%–10% omissions.

Figure 10 is an alternative summary of the information in Figure 9, here collapsed over word position. Averaged over the word-position effects just described, the differences in the error-type patterns for the three developmental sound classes form a generally more coherent picture. Errors on Early-8 sounds are most frequently omissions, with the relative percentage of omissions increasing with age level. Errors on the Middle-8 sounds are most frequently omissions and substitutions. Finally, beginning at approximately 7.5 years, errors on the Late-8 sounds are most frequently distortions.

Summary

To summarize the error pattern data in speech-sound normalization, the progression of error types from omission to substitution to distortion interacted with developmental sound class and word position. The Early-8 sounds were more often omitted, the Middle-8 more often omitted and substituted, and the Late-8 were more often distorted. In general, omissions and substitutions increased from word-initial to word-final position.

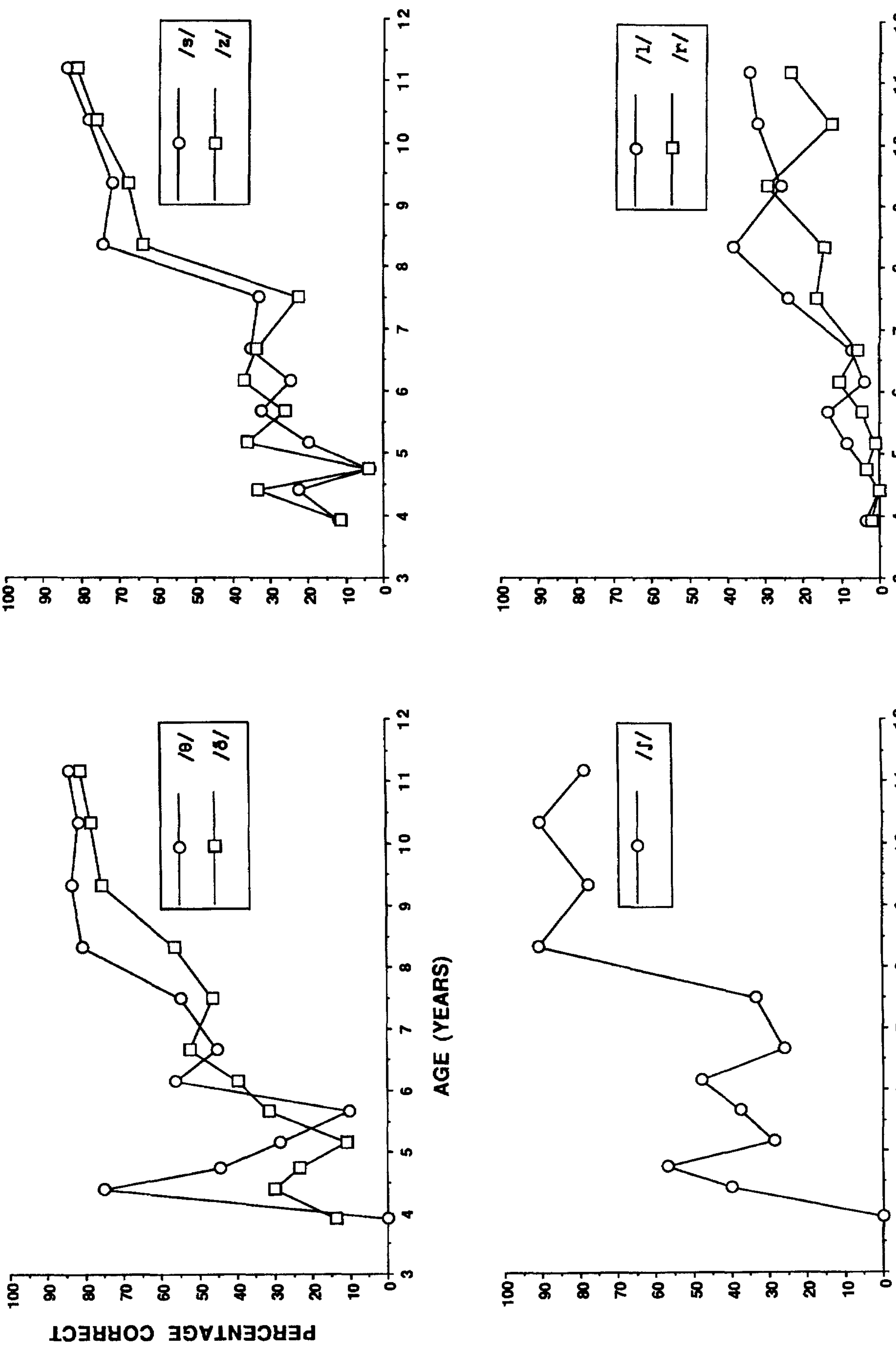

FIGURE 8. Normalization plots for 7 of the Late-8 sounds for the 10 speech-delayed children.

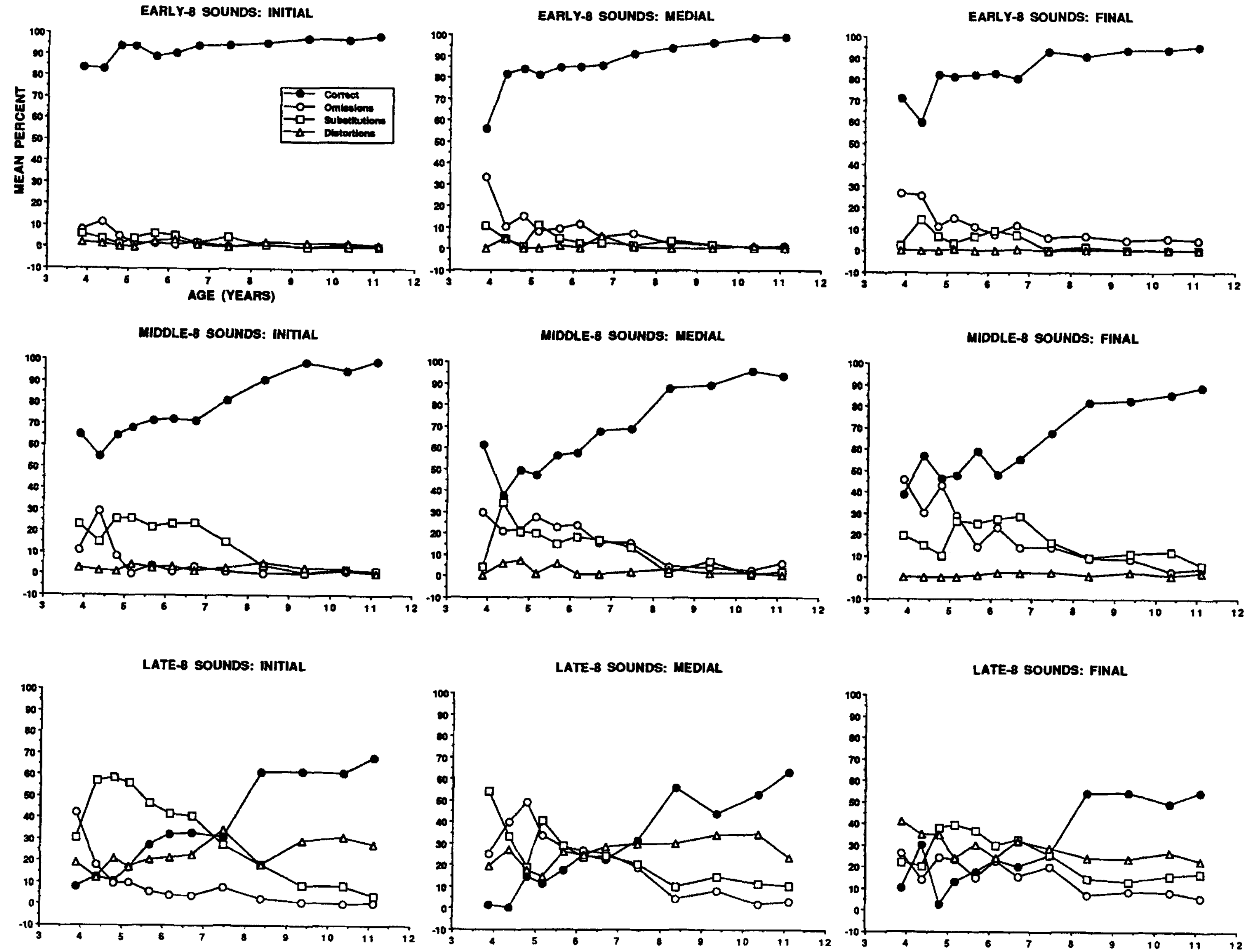

FIGURE 9. Averaged error patterns observed in the 10 speech-delayed children during the period of study. The nine panels illustrate the interaction over time of Developmental Sound Class (Early-8, Middle-8, Late-8) × Word Position (word-initial, word-medial, word-final) × Articulation (correct, omissions, substitutions, distortions).

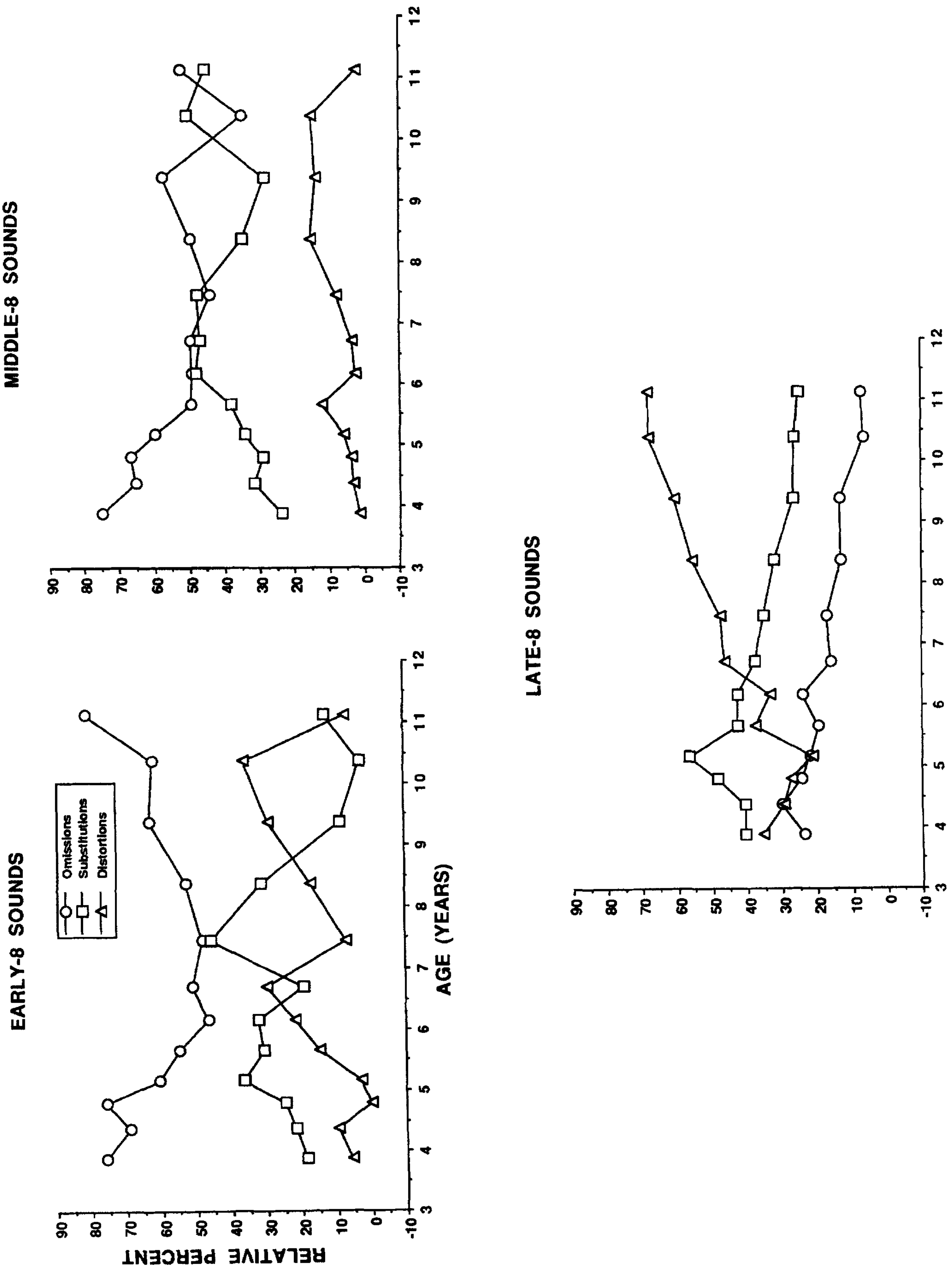

FIGURE 10. Averaged error patterns during the study collapsed over word position.

Conclusions

Six primary findings from this study can be summarized as follows:

1. There is no one invariant sequence of speech-sound normalization acquisition or error-pattern followed by all children acquiring speech normally or normalizing a developmental phonological disorder. Even when group-averaged, there is no one sequence of speech-sound acquisition or error-patterns that has high stability across studies of normal acquisition or short-term or long-term normalization of a speech disorder.

2. Individual and group-averaged similarities in the sequence and error patterns of normal speech-sound acquisition and short-term and long-term normalization of disorders begin to emerge when (a) cross-tabulated by the independent variables of sampling mode and word-position (and singleton-cluster status) and (b) subgrouped by dependent variables based on either developmental sound classes or phonetic features.

3. When examined at the group-averaged level by the independent and dependent variables in (2) above, long-term speech-sound normalization of a developmental phonological disorder follows the same sequence and is characterized by the same error patterns as occur in normal speech acquisition.

4. For children with moderate-to-severe speech-sound involvement when first identified during the preschool period, the average temporal delay in achieving nearly-complete long-term speech-sound normalization is 5 years.

5. The approximately 5-year period of long-term speech-sound normalization is characterized by two periods of more rapid gains from approximately 4 to 6 years and 7 to 8.5 years, interspersed with a period of relatively slow growth from 6 to 7 and after 8.5 years.

6. The persistence of distortion errors on /s/-/z/, /r/-/ɝ/-/ɚ/, and /l/ (as well as some other sounds) past approximately 9 years is likely in children with moderate-to-severe speech delays identified at preschool ages.

Theoretical Issues

The primary theoretical issues prompted by these findings on long-term speech-sound normalization concern the neurodevelopmental correlates of speech acquisition. After approximately 8.5 years, each of the children in this study evidenced a clear slowing of normalization, with the exception for some children of continued but slower gains in the correct articulation of /s/ and /z/. Although on a percentage basis their speech was nearly normalized by 8.5 years, most children continued to have deletion or substitution errors on one or more of the Late-8 sounds in addition to the predominant distortion errors.

One compelling theoretical explanation for the slowing of normalization at approximately 8.5 years is to invoke some form of the critical period perspective discussed by Lenneberg (1967) and more recently by Locke (1994). This perspective presumes that the capacity for language develops within a maturational envelope that begins to close at 8 to 9 years of age. Support for this critical or maximally sensitive period for language acquisition includes studies of foreign language accent and plateaus in language development, with retardation beginning at approximately 8 years. Following this perspective, one interpretation of the present data is that (a) the speech acquisition of these children was, for some reason, literally *delayed*; (b) normalization processes reached a species-general terminus period, past which little or no further normalization occurred; and (c) if not corrected by the end of this critical period, remaining errors persisted as residual speech-sound errors.

Although the present data are consistent with the general concept of a developmental window, the concept would become even more attractive if it could provide specific explanation for two other findings. First, stronger support for the relevant cognitive versus speech-motor correlates of a critical period would involve associations with some metric underlying the sequence of speech-sound acquisition and normalization—or at least some ontogenetically principled scale underlying the developmentally stable classes termed the Early-8, Middle-8, Late-8 sounds. Second, unaddressed is the question of the developmental processes that may underlie the two periods of accelerated normalization or, alternatively, of the plateaus in normalization from approximately 6–7 years and after 8.5 years. Overall, however, the primary finding that normalization processes appear to slow down before all errors are corrected provides strong support for some form of an age-based developmental window for speech acquisition. Specifically, regardless of the absolute levels of cognitive and speech involvements, normalization of at least some speech-sound distortions appears to be markedly less probable after approximately 8.5 years. Further speculation in relation to alternative theoretical views of phonological acquisition would be inconsistent with the descriptive purposes of this prospective study. For example, although it might be appealing to interpret the observed plateaus as support for stage-based models of normal phonological acquisition, such argument would exceed the methodological constraints of these data.

Clinical Issues

The findings summarized at the beginning of this section might provide some perspective on the long-term clinical expectations for children with moderate to severe developmental phonological disorders. Three issues warrant comment.

First, it should be emphasized that the children in this study constituted a group with significant speech-language involvement. This longitudinal study was initiated nearly two decades ago, predating the major shifts in phonological theory, assessment procedures, and service delivery perspectives that characterize contemporary activities in developmental phonological disorders. For example, children selected for participation had significantly more speech involvement than the children studied by Shriberg and Kwiatkowski (1994) and, as expected, most later received special educational services in schools for associated language and academic needs. None of these children had histories of short-term normalization, defined in the prior paper in this series as normalization by age 6 years. Thus, it is appropriate to limit clinical generalizations to the percentage of children from this sector of the speech-delayed population. Based on Percentage of Consonant Correct status (including only children with *moderate-severe* and *severe* involvement considering the ages of these children at first assessment), this sector is estimated to comprise approximately 42% or less than half of all children identified as having a developmental phonological disorder (Shriberg & Kwiatkowski, 1994).

Second, for counseling caregivers of children with this degree of involvement it seems clear that speech-sound normalization should not be expected to be essentially complete until approximately third grade. This endpoint for normalization precisely coincides with the traditional "wait and see" period used by generations of speech-language pathologists who have observed some children normalize without intervention during this period. In the present situation, these children did receive intervention programming of many types, yet their speech errors persisted until approximately 8.5 years when most, but not all, speech-sound errors were resolved. The types of intervention programming they received reflected the state of clinical practice in the late 1970s and early 1980s, raising the question of whether current clinical techniques in child phonology might yield more effective and specifically more efficient gains. Perhaps the best use of these clinical data from the perspective of caregiver expectations is as a benchmark for the outer boundaries of speech-sound normalization. Barring other complications in the individual or his or her service delivery history, children similar to those described in this study might be expected to follow the same time course of normalization of the Early-8, Middle-8, and Late-8 sounds described in this report.

Finally, these findings for rates of speech-sound normalization in relation to the sequence and error-type findings would seem to challenge contemporary speech-language pathologists and researchers to examine the timing of their intervention programs. Hodson and Paden (1991) report that for most children an intensive cyclical program of intervention provided during preschool years results in intelligible speech warranting clinical dismissal after approximately 30 hours of clinical work, with a maximum reported to be 72–91 hours over an 18-month period. Other contemporary treatments based on a diversity of cognitive, motor-speech, and descriptive linguistic frameworks also claim to be effective in rapid remediation of children having speech-language disorders (cf. Bernthal & Bankson, 1993). In light of the periods of more accelerated versus flat normalization growth observed in the present data, two relevant clinical questions arise: (a) Does intensive early speech intervention, especially within certain felicitous time periods, increase the probability of short-term rather than long-term normalization? and (b) Is the selection and sequencing of phonological targets more crucially tied to a child's current phonological system or, alternatively, to the child's chronological age? A maximally efficient clinical technology might someday be based on readily calculated trajectories of speech-sound normalization, with intervention services accelerated during optimum growth periods.

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Appendix

Criteria for Speech-Sound Normalization

Although Sander (1972) argues for viewing *customary production* as the point at which at least 50% of children produce a sound correctly and *mastery* as the point at which at least 90% of children produce a sound correctly, most of the widely cited normative studies have used the intermediate mastery percentage of at least 75% of children (cf. Arlt & Goodban, 1976; Prather et al., 1975; Templin, 1957; Wellman et al., 1931). In the present study, calculation of normalization sequences for all data sets (i.e., for the Hoffmann, 1982, data as well as data for the present subjects) is based on the earliest age at which 75% of responses were judged to be phonetically correct, using the response definitions for narrow phonetic transcription described in prior reports (Shriberg, 1986; Shriberg & Kent, 1982; Shriberg et al., 1984). The 75% correct criterion is also used for comparisons to the Smit et al. (1990) data, which were originally cast as age-based percentages of correct sounds (i.e., total correct responses divided by total obtained responses), rather than by the percentage of children producing the sound correctly.

For conversational speech sample analyses, where direct comparison with traditional normative studies is less appropriate, the criteria for a normalized speech sound was set at 90% correct tokens (cf. Sander, 1972). Transcription of all intended consonants (and vowels-diphthongs) in the conversational speech samples yielded an average of approximately 135 (76%) more consonant tokens (M = 313.4 consonants) per sample than obtained from transcripts of the articulation test data (M = 178.5 consonants).

When data from either the articulation tests or the conversational speech samples are collapsed across independent variables—for example across word position or across gender—the analyses are based on recalculation of percentages using the appropriate new numerators and denominators.