PHONOLOGICAL VOWEL DISORDERS: A CASE STUDY

by

LAUREN JANE PEGG

B.A., The University of Western Ontario, 1986

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF

THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

in

THE FACULTY OF GRADUATE STUDIES

(School of Audiology and Speech Sciences)

We accept this thesis as conforming

to the required standard

THE UNIVERSITY OF BRITISH COLUMBIA

April 1991

© Lauren Jane Pegg, 1991
In presenting this thesis in partial fulfilment of the requirements for an advanced degree at the University of British Columbia, I agree that the Library shall make it freely available for reference and study. I further agree that permission for extensive copying of this thesis for scholarly purposes may be granted by the head of my department or by his or her representatives. It is understood that copying or publication of this thesis for financial gain shall not be allowed without my written permission.

Department of **Audiology & Speech Sciences**

The University of British Columbia  
Vancouver, Canada  

Date **April 29, 1991**
Abstract

Phonological Vowel Disorders: a case study

The purposes of the present study were: 1) to provide descriptions, both phonological and acoustic, of the vowel system of a child who exhibited a phonological disturbance in his vowel system, and 2) to examine the effects that intervention targeting consonants would have on his vowel system. No specific hypotheses were proposed, although it was implied that there would be some effect.

The subject, S, was one of six subjects in a doctoral research study investigating the application of non-linear phonological theory to the assessment and remediation of developmental phonological disorders. The data were selected from the initial assessment session and a reassessment after two blocks of intervention. Both phonological and acoustic analyses of the data were performed. Acoustic measurements included the fundamental frequency and the frequencies of the first and second formants for each phone.

The data showed that S had a large phonetic inventory of vowels with a high proportion of vowel errors. Phonemes exhibited considerable variability but one primary phone could usually be identified. Significant in the phonological description were the following: 1) a high front vowel, a back rounded vowel, a low vowel, and a central vowel were among those most accurately produced by S, 2) there were a significant number of errors in the non-high, unrounded phonemes, and 3) /u/ exhibited a high proportion of errors. In general, errors were
not sensitive to consonantal context. Acoustically, while the formant patterns for each phone differed from the others, S's vowels were found to be different in some ways from normal. Specifically, the frequency of F2 for his back vowels is higher than expected and the frequency of F1 for /a/ is lower than expected. In addition to some differences in formant frequency, the acoustic data on S's vowels show much more variability than normal.

Changes in the data occurred, both phonologically and acoustically, between the pre- and post-treatment assessment. Changes included: 1) improvement in the accurate production of /u/, 2) shifts in the phonetic representation of non-high, unrounded vowels, 3) a decrease in random phonemic error, 4) a decrease in the second formant frequency of back vowels and an increase in first formant frequency of /a/, 5) a decrease in variability of both first and second formant frequency, and 6) a decrease in fundamental frequency. While it was possible to describe differences between the pre- and post-treatment data, it was not possible to ascribe these changes solely to intervention. It is difficult to know whether intervention had a direct effect on vowel production or whether the changes which occurred were more general effects of intervention or simply natural events, coincidental with the intervention program.
Table of Contents.

Abstract ........................................................................................................................................... ii
List of Tables ................................................................................................................................... vii
List of Figures ................................................................................................................................. viii
Acknowledgement ............................................................................................................................ ix

Chapter
1. Introduction ................................................................................................................................. 1
2. Theoretical Issues ......................................................................................................................... 4
   2.1 Phonological Issues .................................................................................................................. 4
       Markedness theory ....................................................................................................................... 4
       Non-linear phonology .................................................................................................................. 5
       Underspecification theory .......................................................................................................... 8
       The representation of English vowel phonemes ....................................................................... 8
       Rules affecting vowels ............................................................................................................... 11
   2.2 Acoustic Phonetic Issues ....................................................................................................... 13
       Spectral Analysis ......................................................................................................................... 14
       The acoustic characteristics of vowels .................................................................................... 15
3. Children's Vowel Production: Normal Development ................................................................. 18
   3.1 Phonological Studies .............................................................................................................. 18
       Diary studies .............................................................................................................................. 19
       Cross-sectional studies ............................................................................................................ 28
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factors affecting vowels</td>
<td>31</td>
</tr>
<tr>
<td>Summary</td>
<td>36</td>
</tr>
<tr>
<td>3.2 Acoustic Phonetic Studies</td>
<td>37</td>
</tr>
<tr>
<td>Summary</td>
<td>45</td>
</tr>
<tr>
<td>4. Children’s Vowel Production: Atypical Development</td>
<td>47</td>
</tr>
<tr>
<td>4.1 Phonological Studies</td>
<td>47</td>
</tr>
<tr>
<td>Summary</td>
<td>59</td>
</tr>
<tr>
<td>4.2 Acoustic Phonetic Studies</td>
<td>60</td>
</tr>
<tr>
<td>Hearing impaired children</td>
<td>61</td>
</tr>
<tr>
<td>Language Delayed children</td>
<td>64</td>
</tr>
<tr>
<td>Summary</td>
<td>64</td>
</tr>
<tr>
<td>4.3 Intervention Studies</td>
<td>65</td>
</tr>
<tr>
<td>5. Methodology</td>
<td>68</td>
</tr>
<tr>
<td>Subject</td>
<td>68</td>
</tr>
<tr>
<td>Data</td>
<td>69</td>
</tr>
<tr>
<td>Method</td>
<td>69</td>
</tr>
<tr>
<td>6. Results and Discussion</td>
<td>73</td>
</tr>
<tr>
<td>6.1 Phonological Analysis</td>
<td>73</td>
</tr>
<tr>
<td>Pre-treatment results</td>
<td>73</td>
</tr>
<tr>
<td>Post-treatment results</td>
<td>77</td>
</tr>
<tr>
<td>Comparison of pre- and post-treatment results</td>
<td>82</td>
</tr>
<tr>
<td>6.2 Acoustic Analysis</td>
<td>86</td>
</tr>
</tbody>
</table>
List of Tables

Table 2.1 Feature specification for English phonemes ........................................ 11
Table 2.2 Phonetic inventory of English vowels ................................................... 13
Table 3.1 Selected results from acoustic studies of children's vowel production ........................................ 44
Table 6.1 Accuracy rates for vowel phonemes before treatment .......................... 74
Table 6.2 Confusion matrix for monophthong vowels pre-treatment ..................... 75
Table 6.3 Accuracy rates for vowel phonemes after treatment .............................. 78
Table 6.4 Confusion matrix for monophthong vowels post-treatment ..................... 80
Table 6.5 Comparison of featural groupings before and after treatment ................. 86
Table 6.6 Mean formant frequency values for 7 phones before treatment ............... 87
Table 6.7 Mean formant frequency values for 7 phones after treatment ................. 88
Table 6.8 F1 and F2 standard deviations for each phone across treatment ............... 90
Table 7.1 Hypothetical feature specification for S ............................................. 97
List of Figures

Figure 2.1 Basic tree structure ........................................................................................................ 7

Figure 6.1 Histogram showing the changes in accuracy rates (% correct) from pre- to post-treatment for each phoneme ........................................................................... 83
For their contributions to this thesis, I would like to thank:

Dr. John Gilbert, my thesis supervisor, for his guidance and wisdom, and for knowing when not to ask for the next chapter.

Dr. Barbara Bernhardt, my second reader, for providing the data on which this thesis is based and for her observations and comments about S.

Dr. Janet Werker, for allowing me to use her lab space and equipment and for including me in the activities of the lab.

My current employer, The Vancouver Neurological Centre, and especially Kate Wishart, for giving me the flexibility I needed to begin a professional career and finish this thesis concurrently.

My mom, the soon-to-be Dr. Judith Pegg, for her help with statistics and other tasks, but mostly for inspiring me.

My dad, David Pegg, for his moral support and for putting a roof over my head.

And to the rest of my family and friends whose belief in me made this all possible.

This thesis was supported in part by a grant from the National Sciences and Engineering Research Council.
1. Introduction

Previous research on normal and disordered phonological development has focused primarily on the consonant system, although some information concerning vowels exists. Vowels are of interest in developmental speech research because they differ from consonants in many ways which may impact on their acquisition. This thesis is concerned primarily with the phonological and acoustic phonetic aspects of vowels discussed in section 2.1.

In the phonological literature, information about vowel development comes primarily from subjects younger than 3 years, since it is generally accepted that the vowel system is acquired by the age of 3;0 (Templin, 1957). In contrast, acoustic phonetic studies of children's vowel production tends to focus on children over 3 years of age. This is due, in part, to the fact that the high fundamental frequency of young children's voices makes spectrographic analysis difficult. The separation of methodologies by age reflects the fact that, although phonological acquisition of the vowels appears to be complete by the age of 3 years, phonetic development continues well beyond that point.

The methodologies employed in the present study, then, are well justified. A phonological analysis is appropriate for comparison with what is known about the normal course of phonological vowel development, even though this subject is older than 3, and an

---

1 That there is relatively little acoustic data on any children's speech is probably also accounted for by the fact that the high F₀ of children's voices makes spectrographic analysis difficult.
acoustic phonetic analysis is appropriate for an evaluation of the subject’s phonetic
development. Both aspects of his vowel production will have an impact on his intelligibility
and, therefore, both need to be evaluated.

Studies of phonologically disordered children with vowel errors\(^2\) are rare. Those that
exist tend to describe disordered phonology rather than examine the effects of intervention.
Only the literature surrounding the vowel production of deaf speakers deals directly with the
issue of the efficacy of intervention in the remediation of vowel disorders. In one such study
(Osberger, 1987), subjects were hearing-impaired school-aged children who received
intervention for vowels. The present study contributes to this area of the literature by
providing an examination of the effects of intervention for a phonologically disordered child.
What is unique about this study is that changes in the vowel system were examined although
intervention was focused only on the consonant system during the period examined.

A limitation of the acoustic data from previous studies on normal vowel development
is that only phonetically accurate phonemes have been analyzed. There has been no acoustic
phonetic analysis of normal children’s phonemic mismatches. In the literature on children
with phonological disorders, a few studies have used acoustic phonetic methods to look at the
vowel production of special populations such as Down’s Syndrome children (Pentz, 1987) and
deaf or hearing impaired children (Gulian, Hinds, and Fallside, 1983; Rubin, 1983), but none

\(^2\) Terms such as "error", "correct", and "incorrect" are used descriptively to characterize
mismatches between child and adult forms. I do not intend to imply that when children’s speech
does not match adults’, it is wrong.
have been found for phonologically disordered children. The present study contributes acoustic analyses of both correct and incorrect vowel productions of a phonologically disordered child.

The purposes of the present research were 1) to examine the vowel production of a phonologically disordered child who exhibits vowel errors, and 2) to examine the effects that intervention targeting consonants has on his vowel system. Before presenting the data and analysis, I will discuss the theoretical issues surrounding vowels and review the phonological and acoustic phonetic literature on vowel development.
2. Theoretical Issues Surrounding Vowels

Before discussing the development of vowels by typical and atypical language learners, a brief discussion of the theoretical issues surrounding vowels is necessary. In this section, I investigate vowels from a theoretical perspective, examining their phonological and acoustic phonetic nature. I begin, in each case, with a discussion of general characteristics and then move to a discussion specific to the vowels of English.

2.1 Phonological Issues

Three issues require discussion here: markedness theory, non-linear phonology, and underspecification theory. I will discuss each generally and then specifically, with respect to English vowels.

Markedness Theory

Markedness theory, in general, encompasses the idea that some linguistic phenomena are universally more common than others and that those phenomena which are more common are less marked and, therefore, more likely to be given by Universal Grammar (UG). Specific to phonological representation, markedness theory implies that, for each feature of

---

1 Universal Grammar is the term used to describe innate knowledge about language. A child is assumed to operate on the basis of UG until the language in his environment provides evidence that is inconsistent with UG. The child will then adjust his own system to reflect what he is perceiving.
either a consonant or a vowel, there will be a universally marked and a universally unmarked value. That is, one value of the feature is given by UG to be the "default" value. One way of determining markedness is by surveying the world's languages and determining those feature values which occur most frequently. Since unmarked features are assumed to be a part of UG, the child's natural endowment for language, it follows that unless a child perceives the unmarked value to be inconsistent with the language he is learning, he will continue to use it. This has certain consequences for phonological acquisition. Specifically, the least marked feature combinations should be the first (or, at least, the most common or most frequently correct) to appear in acquisition. The unmarked place features for vowels are [-round], [+back], [-high] and [-low]. The least marked vowel phoneme is /ə/.

Non-linear Phonology

The study of phonology, in general, involves the examination of speech sounds and sound sequences with respect to their representation and the rules which apply to them. The most widely acclaimed current phonological theory assumes features to be the basic combinatorial units of phoneme representation and the units which specify rules. In traditional generative phonology, phonemes are represented by an unordered set of features, or a feature bundle. Features within a segment have no necessary relationship to each other or to features in other segments. In addition, traditional generative phonology has not provided an adequate representation of supra-segmental features such as stress and tone.

Traditionally, phonological rules are represented as transformational statements
including structural descriptions of the segment(s) affected by the rule, the environment required for the rule to apply, and the resulting segment. There are no principled reasons for some rules to be more natural than others, for some groups of features to pattern together more often than others, or for non-adjacent segments to affect each other. As a result, phonologists taking a traditional view of phoneme representation and rules have not been able to explain adequately, although they have described, phonological phenomena involving supra-segmental features, natural classes, frequently occurring sets of features, and non-adjacent segments (e.g., consonant and vowel harmony).

In contrast with the two-dimensional representation seen in traditional generative phonology, non-linear phonology provides a three-dimensional representation of sounds. Features within a segment are in a hierarchical relationship with each other and are related to features in adjacent segments on tiers. The hierarchical structure also includes supra-segmental features. It has the advantage of assigning features such as stress to whole syllables rather than segments. It gives some structure to segmental features, justifying the existence of natural classes of sounds and explaining why some features pattern together in rules and others do not, and it gives a principled way for apparently non-adjacent segments to be adjacent at some level of representation. The supra-segmental, or prosodic, level includes tiers for phonological words, feet, and syllables. The segmental level includes functional groupings of features, hierarchically organized by nodes. The specific structure of the hierarchy is currently under debate but the general features and principles which govern it are widely accepted. An example of the basic tree structure is shown in Figure 2.1.
In non-linear phonology, phonological rules are explained through tier association. That is, adjacent constituents (features or groups of features under a node) affect each other in principled ways. Four types of operations are possible: spreading, delinking, inserting, or deleting (Bernhardt, 1990 after Goldsmith, 1976). A spreading operation results in surface assimilation or coalescence: a constituent spreads, or links to an adjacent segment, resulting in a similarity between the two segments. Delinking results in dissimilation or delinking. Insertion and deletion are the addition or removal of constituents. In each case, adjacency is
required, that is, in order for one segment to effect a change in another, the two must be adjacent at some level of representation. Tier association is also constrained in that association lines must not cross.

In sum, the shift from traditional generative phonology to non-linear phonology includes changes in the perspective on both representation and rules while features remain the basic structural units. Rather than representation being two-dimensional and unordered, it is three-dimensional and hierarchically organized. Phonological change is, in part, a consequence of representational structure rather than entirely explained by descriptive rules.

Underspecification Theory

Underspecification theory states that the underlying representations of sounds are minimal. There are two current views of underspecification: radical and contrastive. In radical underspecification only those feature specifications that are not predictable from other aspects of the phonological system are included in the underlying representation (Archangeli, 1988). In contrastive underspecification, values are included if they are required to define contrast in the underlying system (Steriade, 1987). In the dissertation on which this thesis is based, Bernhardt (1990) takes a radical underspecification view. This view will also be adopted here.

The Representation of English Vowel Phonemes

Descriptively, vowel specifications for English must include information about tongue
height, tongue advancement (front/back dimension), lip rounding, and tenseness. It is often suggested that vowels should not be represented by the same feature system that has been developed for consonants since they differ in both articulatory and acoustic characteristics. Specifically, a system of binary features can be shown to be inadequate in accurately describing vowel systems (Clements, 1989b). As a result, several competing feature systems have been proposed to account for the representation of vowels².

First, there are systems in which features are multivalued rather than binary (Ladefoged, 1989). These systems attempt to capture the more continuous nature of vowel articulation and resulting acoustic parameters but fail to reflect natural phonological classes of vowels. Second, there are systems which propose stacking one-valued features, or vowel particles (Schane, 1984b). These systems also capture the more continuous nature of vowels by allowing unlimited combination and stacking of the three particles /i/, /a/, and /u/. They also account for differences in vowel complexity (or markedness) by the number of particles necessary to specify the vowel. One-valued systems, however, do not accurately reflect natural classes of vowels and they do not provide a way of representing mid-central unrounded vowels (e.g. /ə/). Third, Clements (1989b) proposes a system in which vowel features are hierarchical. His proposal has the advantage of being consistent with feature theory relevant to consonants while also providing a way of representing the more continuous nature of vowels. Briefly, height, which is the parameter he discusses, is recognized as a unitary feature and gradations of height are represented by levels in a hierarchy. An

² The descriptions of these competing systems comes from Clements (1989b).
argument for hierarchical features of advancement could also be made.

In spite of the dispute over vowel feature systems and the recognition that binary feature systems are somehow inadequate for vowel representation, binary features are still the most common way of representing vowels, particularly in the literature concerning clinical phonology. For this reason, I have adopted a binary feature system incorporating the theories of markedness and underspecification to be used in the non-linear representation of vowels. Table 2.1 contains a description of the underspecified representations for the vowel phonemes of English.

The non-linear representation of vowels is consistent with the basic tree structure in Figure 2-1 but it is necessary to recognize that there must be some differences between vowels and consonants. Clements (1989a) has suggested that consonants and vowels are non-adjacent at the place node and below. That is, there is a separate place node for consonants and vowels (referred to as C-place and V-place nodes). This would imply that tier association between consonants and vowels should not occur for features below the place node and harmonies (tier association between vowels across consonants and vice versa) should not occur for features above the place node. This is the view of vowel representation that I shall adopt.
Table 2.1 Feature specification for English phonemes (adapted from Bernhardt, 1990)

<table>
<thead>
<tr>
<th>Phoneme</th>
<th>Dorsal Node</th>
<th>Labial Node</th>
</tr>
</thead>
<tbody>
<tr>
<td>/i/</td>
<td>[-bk]</td>
<td></td>
</tr>
<tr>
<td>/e/</td>
<td>[-bk],[-hi]</td>
<td>/ə</td>
</tr>
<tr>
<td>/æ/</td>
<td>[-bk],[-ts]</td>
<td></td>
</tr>
<tr>
<td>/æ/</td>
<td>[-bk],[-ts]</td>
<td></td>
</tr>
<tr>
<td>/ʊ/</td>
<td>[-ts]</td>
<td></td>
</tr>
<tr>
<td>/u/</td>
<td>[-ts]</td>
<td>[+rd]</td>
</tr>
<tr>
<td>/ʊ/</td>
<td>[-hi]</td>
<td>[+rd]</td>
</tr>
<tr>
<td>/o/</td>
<td>[-hi]</td>
<td>[+rd]</td>
</tr>
<tr>
<td>/ʌ/</td>
<td>[-hi],[ts]</td>
<td>[+rd]</td>
</tr>
<tr>
<td>/ʌ/</td>
<td>[-bk]</td>
<td>[-lo]</td>
</tr>
<tr>
<td>/ɑ/</td>
<td>[+lo]</td>
<td></td>
</tr>
</tbody>
</table>

1. All vowels are marked as [+son] under the root node.
2. No laryngeal node features are marked since [+son] implies [+voice].
3. Diphthongs are treated as complex segments with two root nodes. The second component in the diphthong is always [-ts].
4. Features are abbreviated as follows:
   [hi] = [high]   [bk] = [back]   [rd] = [round]
   [lo] = [low]    [ts] = [tense]

Rules Affecting Vowels

The vowel length distinction seen in some other dialects of English does not exist in
the dialect of the Vancouver area. As a result, traditionally short vowels such as /ɪ/ and /ʊ/ sometimes become centered diphthongs with [ə] off-glides. The phonemes /ɛ/ and /ɔ/ are also subject to diphthongization resulting in [eɪ] and [ɔu] respectively. The two diphthongs /aɪ/ and /au/ are subject to Canadian raising. That is, they become [AI] and [AU] in closed syllables when followed by voiceless consonants (Bernhardt, 1990). There is also some variation which occurs in the low vowels series which appears to be phonetic free variation (Bernhardt, 1990). The low front vowel /æ/ can appear as [a], but this is rare, and the low back vowel /ɑ/ appears variously as [a], [ɑ], or [ɔ].

In addition to the above, which do not depend on phonetic context, the phoneme /t/ has several effects on the vowels of English. Specifically, contrasts are often neutralized in the environment of /t/ (e.g. /i/ and /ɪ/ surface as [i], /o/ and /ɔ/ surface as [ɔ], /u/ and /u/ surface as [u], and /ɛ/, /ɛ/, and /æ̃/ all surface as [æ]). These rules, however, are opaque and are not easily learned by a child. That is, the underlying representation is hypothetical - there is no evidence that the underlying forms are different from the surface forms. The rules may represent real shifts historically but they may not reflect real phonological neutralizations synchronically.

Table 2.2 gives a phonetic inventory of English monophthongs and diphthongs in the dialect of Vancouver, B.C..
Table 2.2 Phonetic Inventory of English Vowels

Monophthongs

\[
\begin{array}{ccc}
& i & u \\
i & e & a \\
\varepsilon & \varepsilon & \circ \\
\varepsilon & a & \partial \end{array}
\]

Diphthongs

\[
\begin{array}{c}
\varepsilon i \\
\varepsilon u \\
\alpha i \\
\alpha i \\
\alpha u \\
\alpha u \\
\i c
\end{array}
\]

2.2 Acoustic Phonetic Issues

Acoustic phonetics involves the study of the acoustic waveform of speech to discover information about speech production (and perception) that is not available via other methods such as transcription. The notion of using acoustic information to study speech was formalized in Gunnar Fant's monograph "Acoustic Theory of Speech Production" (Fant, 1960). In Fant's theory, the vocal tract is seen as a filter or resonator, of varying size and shape, which is set into vibration by the laryngeal source. By examining the nature of the

\[\text{\footnote{There is some question as to whether this low back rounded vowel does occur in the dialect. It does not appear in any of E's transcriptions.}}\]
acoustic output, it is possible to determine the size and shape of the vocal tract filter. This is done through spectral analysis. I will discuss this methodology and the information it gives.

**Spectral Analysis**

Spectral analysis is traditionally performed using a sound spectrograph. The sound spectrograph is a device that decomposes an acoustic waveform into its component frequencies and represents them visually on a time scale. On a spectrogram, time is represented on the horizontal axis and frequency on the vertical axis. Relative amplitude is represented by a third dimension: darkness. Absolute values of the amplitude at different frequencies can be obtained by taking amplitude sections for individual time periods. There are two general types of spectrograms, wide band and narrow band, although, hypothetically, spectrograms can be made with any bandwidth. Wide band spectrograms perform a frequency analysis using bands of 300 Hz. They are very accurate in the time dimension but less accurate in the frequency dimension since several harmonics (component frequencies of the laryngeal source) are analysed together in a single frequency band. Narrow band spectrograms use bands of 45 Hz and are more accurate in the frequency dimension and less accurate in the time dimension than wide band spectrograms.

The sound spectrograph was developed based on speech production of the adult male and therefore it most accurately analyses the speech of adult males. It has, however, been used effectively to analyse the speech of women and children, whose fundamental frequencies
are higher. Because of the higher fundamental, and resulting widely spaced harmonics, narrow band spectrograms are sometimes ineffective in analysing the speech of women and children since some analysis bands may not contain any frequency information. Nevertheless, information about the acoustic characteristics of women’s and children’s speech has been gathered through spectrographic analysis.

A further development in spectral analysis which is employed in this thesis is linear predictive analysis, or linear predictive coding (LPC). An LPC analysis is similar to an amplitude section but rather than providing the absolute values of amplitude by frequency, it predicts the general shape of the spectral envelope. A time window of approximately 25 msec. is analysed and the shape of the spectrum at that time is displayed. Formant frequencies can be measured directly from the display. LPC analysis does not give information about formant transitions since it only analyses a single time window.

The Acoustic Characteristics of Vowels

Acoustically, vowels are long and intense, as compared with consonants, and are characterized by a continuous acoustic signal. That is, it is possible to move from the production of one vowel to another with minimal changes in intensity. This reflects the more continuous nature of vowel articulation discussed above. Vowels are specified by formant frequencies, or resonances of the vocal tract, rather than by the periods of silence, noise bursts, or high frequency frication noise which specify consonants.
The formant frequencies of vowels are, in fact, their distinctive acoustic features. Although the shape of the frequency spectrum is due to the size and shape of the vocal tract as a whole, some specific relationships between articulatory and acoustic features can be drawn. The first formant (F1) frequency is closely related to, but not entirely determined by, the height of the tongue during vowel production: a high vowel will generally have a lower F1 than a low vowel. The second formant (F2) frequency is closely related to, but, again, not entirely determined by, the degree of backness of a vowel: in back vowels, F2 is generally lower than in front vowels. Because lip rounding results in a lengthening of the vocal tract, it results in a lowering of the frequencies of all formants.

The acoustic vowel space, the area on an F1 X F2 plot within which vowels are represented, illustrates a real limitation on vowel production. The size and shape of that space is, ultimately, determined by the size of the speaker's vocal tract. The point vowels, [i], [a], and [u], define the corners of the vowels space in both the articulatory and acoustic dimensions. If we, as speakers and listeners of the same language, are to understand each other, our vowel spaces (and acoustic and articulatory spaces, in general) must be equal at some level: speakers and listeners must normalize the speech they hear. The issue of the perceptual normalization of speech is particularly relevant to phonological development since

---

5 The process of discovering a consistent relationship between acoustic and articulatory features is a complex one. The search for acoustic invariance is constrained by the technology available for acoustic speech analysis and the constantly evolving theories surrounding phonetic features.

6 From Ladefoged (1982).
children, with their smaller vocal tracts, are unable to reproduce the frequency values they hear in the speech of adults. Children must find a relationship between the size and shape of their vocal tracts and their acoustic output (production and perception) which is the same as that which they perceive in the speech of adults.

In sum, vowels are acoustically defined by formant frequencies, the values of which are determined by the size and shape of the vocal tract. Formant frequencies can be measured through spectral analysis including such methodologies as spectrographic and linear predictive analysis. The use of spectral analysis in studying developing speech may be useful in determining the relationship between children's and adults' speech and in identifying developmental changes.
3. Children's Vowel Production: Normal Development

Published research on children’s vowel production is diverse. Subjects vary in age from infancy through childhood and adolescence and have been compared with each other and adults. Studies have been conducted from both phonological and acoustic phonetic perspectives. Phonological studies have tended to examine vowel production in children below 3 years of age whereas acoustic phonetic studies have tended to look at production in children older than 3 years. Methods of data collection have varied from unstructured observation and recording to structured elicitation or imitation tasks. Data have been transcribed phonetically, analyzed phonologically and acoustically, and subjected to various listening tests. As a result, current knowledge about the development of vowel production is vague and scattered. In a review of the existing literature, I attempt to highlight the facts and illuminate the gaps in our knowledge.

3.1 Phonological Studies: Normal Development

Reports of research on phonological development generally include information about order of acquisition, age of mastery, and types of errors. Based on this information, norms for phonological acquisition are developed. On the one hand, this information is abundant for consonants. Because of the large number of studies on consonant development, currently

---

1 Results are reported as experimenters presented them. It was not the purpose of this thesis to reanalyze data in terms of current phonological frameworks.
accepted norms for acquisition and mastery are well supported by converging evidence, for the most part, from a number of different methodologies. On the other hand, for vowels there is a small body of data from a few different methodologies which are not necessarily divergent but which are, nevertheless, insufficient for developing norms. Data on vowel development can be found in diary studies, cross-sectional investigations, and studies of the factors affecting vowels. No longitudinal group data currently exists. Because of these differences between consonant and vowel data, it is more difficult to form a cohesive picture of the course of phonological development for vowels than consonants. Nevertheless, I will review existing research and draw some tentative conclusions.

Diary Studies

In his seminal work on language acquisition, Velten (1943) presented data from observations of his daughter's language from 11 to 36 months. Although English was the primary language spoken at home, French and Norwegian were also spoken. The data are descriptive of both consonant and vowel development in words. Joan’s first vowel was [a]. She developed a two vowel system seven months later (C.A. 1;6) when [u] appeared, first only for adult [u] or [uw] and then for all mid and high vowels. Velten also described Joan’s acquisition of the voicing contrast in English and its interaction with her vowel system from her 23rd to her 27th month. Before producing a voicing contrast in consonants, Joan used vowel length phonemically to maintain a contrast where syllable final consonant voicing was neutralized or the consonants were absent².

² See later review of Locke (1983).
In her 36th month (2;10), Joan produced a third vowel, [i] which first occurred as an allophone of [u] in unstressed open syllables and then served as a substitute for [i] and [e]. From her 42nd to her 44th month (3;4 to 3;6) Joan produced at least five new vowels which all occurred as allophonic variants of an established phoneme before becoming full phonemes. In order of their appearance, the five vowels were [e, e, o, ə, æ]. Velten commented that soon after the appearance of these vowels, all of Joan’s vowels became phonetically identical to "the corresponding English sounds" with, for example, diphthongization of [e] and [o] to [ei] and [ou]. Joan Velten’s vowel system would therefore appear to have reached adult-like phonetic realization by the age of 3½ years, or shortly thereafter.

Leopold (1947) observed and recorded his daughter’s speech in the first 2 years. Data from English and German for both consonants and vowels were presented. In general, Hildegard’s vowels were produced with some accuracy. That is, although there was variation in her vowel production, at least some of the features of the targetted vowel were maintained. Front/back distinctions were more accurately reproduced than height distinctions. Low vowels were always represented by low vowels, usually [a], high vowels were represented by either high or mid vowels, and mid vowels were the most variable being represented by mid, high, or low vowels. Height distinctions were more consistently reproduced in the front vowels than the back. The process of lowering of vowels was more common than raising. This was explained with reference to the low resting position of the tongue. There was no

---

3 It appears that Velten used the criteria of phonemic contrast to define a phoneme.
notable difference between vowels in stressed versus unstressed syllables except that those in unstressed syllables were more often omitted due to the process of weak syllable deletion.

Leopold identified several stages in Hildegard’s speech development and discussed phonetic and phonemic development in terms of them. The stages are crying (birth to 1 month), cooing (1-2 months), babbling (0;2-1;3), and speaking (0;9 +). He noted that from 0;9 to 1;3, when babbling and speaking overlapped, the distinction between segments in babbling versus speaking is arbitrary, but he makes it nevertheless. In the crying stage, Hildegard produced the vowels [a], [a], and [æ]. Her inventory of vowels expanded in the cooing stage with the addition of [e], [ʌ], [ə], [u], and [u]. The most commonly occurring vowels during this stage were [u] and [u], but they did not appear again in Hildegard’s speech until late babbling/early speech. The central vowels were also not used again until much later in the speaking stage.

The phones [a], [a], and [e] continued from cooing into babbling and then, later, into Hildegard’s first words. In her first words, these phones appeared to function as one phoneme, the first in her vowel system. She used [æ] from the cooing stage into babbling, but in words, /æ/ was realized as [a]. A rare phone in babbling was [i]. However, [i], which first occurred at nearly 2 months and then was babbled frequently at 8 months, and [i] formed the second phoneme class to be acquired in Hildegard’s speech. They occupied a high/high-mid front position in contrast with the low front phoneme previously acquired. At 10 months, [e] first occurred in babbling and then in words at 1;2, but it was not considered
phonemic until 1;5.

Similarly in the back vowels, the first position to be acquired was high. In babbling, [u] and [u] were infrequent. Both phones occurred occasionally in words from 1 year but were inconsistently produced as high back vowels until 1;7. [u] also began appearing as a substitute for /o/ at 1;8 until a mid back position was represented phonemically by [o] or [o] (usually [o]). Both of these phones were uncommon in babbling, in fact, [o] was infrequent in the whole of Hildegard’s first 2 years. The central vowels were the latest occurring phones in speech with [o] not occurring in words until 1;11 and /a/ consistently represented by [a] throughout the reported period.

Leopold summarized Hildegard’s phonemic development in three stages. In the first, the vowel system comprised one undifferentiated group of low vowels. In the second stage, the dimensions of height and advancement both became important and each consisted of two levels, giving a 2X2 system (front-back, high-low). The final stage hypothesized is one in which the two dimensions (height and advancement) are given three levels resulting in a 3X3 system (low-mid-high, front-central-back). At the end of the period of study, the central vowels were weakly established in Hildegard’s speech and the distinctions between some pairs of closely related vowels had not yet been made (e.g. i/ɪ, u/ʊ, and o/ə).

Menn (1976) presented data from her observations of a child, Jacob, from 12 months, 8 days to 20 months, 22 days which included detailed information about both consonant and
vowel development. She presents her data with respect to a model of child phonology which allows for three modes of analysis and two methods of defining targets and range of variation. Briefly, a child may analyse a word as an unanalysed whole, a temporal sequence of segments or syllables, or as a prosodic unit. In any of these modes, the child is hypothesized to define a target in terms of features and the range of variation about that target in a continuously changing manner. Menn looked to the data from Jacob to support her theory.

All but three of Jacob's words appeared to be analysed as sequences of segments and so this mode was chosen as the method of analysis. Data are presented both in a raw form and in a 'digested' form which addresses the theory directly. I will first present the data as Menn sees it and then provide information gleaned from the raw data. The data were divided up into 8 sets, which varied in length, representing shifts in the phonology of the consonant system. Menn examines both "simple vowels", monophthong vowels in single syllable words, and "complex vowels", diphthongs and vowels in two syllable words. In sets 1-4, [æ], [a], and [ʌ] in single syllable words were essentially accurate with the exception of [a] in "doll" which was too far front and then, in week 5, too far back. The pattern of variability for [a] is not explained by either "feature-matching" or "honing-in". The [o] in "no" is highly

---

4 Unfortunately, the same sets were used to describe the vowel data. Any great changes in vowel production that occurred within a set were noted but Menn admits that she may have missed some fine-grained patterns. It is a characteristic of much of the data on vowel development that vowels are considered secondarily to consonants. As a result, our current knowledge is likely to be incomplete.
variable but this can be explained by the variability of this word in adult speech.  

Jacob’s complex vowels appear to support the idea of a discretely specified target and a continuously specified range. For example, the two vowels in "thankyou" are, at first, subject to a number of errors. Over time, they gradually pull apart becoming distinct from one another. Menn warns, however, that this gradual improvement could be due simply to increasing articulatory motor skill. Another example from the complex vowels is the discrepancy in the range of variation of [æw] allowed in "down" versus "round". There is no lexical explanation for the wide range seen in "down" and the narrow range seen in "round" and so it seems that Jacob is more careful to be exact when producing "round". He could not do this if his range of variation was specified discretely in features since the features specified would be the same for both words.

Two other arguments are made based on the data. The first is that Jacob appeared to have a "strong internal organization" in his vowel system by the age of 16;30. Evidence of this organization comes from the disruption that occurred in Jacob's system while he was acquiring [ɔ]. It appears that [ɔ], which was previously almost always correct, was in error 50% of the time during set 7 when [ɔ] was produced correctly a fair proportion of the time.

---

5 Adults can produce "no" in a variety of ways such as "nope", "nuno", and "no-no-no..." and rely on lexical, in addition to phonological, information to specify the word.

6 Improving articulatory competence could be a factor in variation and does not discount Menn's theory.

7 Menn points out, however, that since "down" and "round" are the only two words which target [æw] until set 8, arguments which do not argue against feature analysis can be made.
Furthermore, the substitution for [o] was usually [u], a substitute that had never occurred for [o] before. Jacob appeared to be making room in his system for a new back rounded vowel. It is important to note that Jacob did recognize [ɔ] as a distinct target before he was actually able to produce it.

The final argument made is that Jacob used a prosodic analysis for some forms. Specifically, two syllable words were difficult for Jacob but the patterns of error do not suggest that Jacob always simplified the forms by assimilating vowels. In fact, not only did he maintain a distinction between different vowels in two syllable words, he actually dissimilated some pairs of vowels that should have been the same or highly similar. Jacob appeared to have performed a "horizontal prosodic analysis", an abstraction of the pattern front vowel-back vowel, which he applied to two syllable words.

The raw data show that, phonetically, Jacob was producing the range of English phones from the outset of the study with the exception of [u], which did not occur until age 14;24 (set 2). This is not to say that Jacob never produced [u] at the beginning of the study, merely that he did not do so during the recording sessions. Jacob’s speech was quite variable throughout the period of study although his simple vowels were somewhat more consistent than his complex ones, at least until set 8 (19;29). The number of simple phonemes

---

It appears that [u] was a target only in the word "thankyou" during the first few recording sessions. Since Jacob had more difficulty accurately producing vowels in two syllable words and since no single syllable word targetting [u] was recorded, we cannot be sure that Jacob was unable to produce [u].
attempted either increases of stays the same from one set to the next. In set 7, as mentioned by Menn, both [o] and [ɔ] are highly variable but there is still consistency in the other vowels. In set 8, it seems as if the phonological system has expanded too rapidly for Jacob to maintain the amount of internal consistency seen previously. Presumably, Jacob will eventually get this larger system under control.

Ingram (1976) reanalysed the data on vowel development from the above-mentioned diary studies in an attempt to provide evidence of the early stages in phonological vowel acquisition proposed by Jakobson (1968). Briefly, Jakobson proposed that the first vowel in the phonological system of children is [a] followed by either [i] or [u] or both. Ingram presented a phonetic inventory of vowels in the first 25 words of children from the four diary studies and concluded that, since each child’s system contained [a] and either [i] or [u], Jakobson’s claims were supported. There are two problems with this conclusion. The first is that two of the children’s systems contained vowels other than [i], [u], and [a], and only the most complete of these contained all three vowels. Longitudinal data on the order of appearance of the vowels is necessary to support Jakobson’s claims. The second problem is that Ingram used phonetic inventories to validate claims about phonological development. His conclusion would be more strongly supported if an examination of phonological function of the phones was also given. The only conclusion that may be drawn is that the data presented by Ingram are consistent with Jakobson’s claims. In order to support his claims,
phonological analysis over time would be required.

In sum, the data from the early speech of Joan, Hildegard, and Jacob are diverse. Some conclusions may, however, be drawn. All three children used some group of low vowels as their first functional vowel phoneme (only one phone in the speech of Joan). Next, all three children built a two level contrast based on height. Joan and Jacob chose to use a high back phoneme while Hildegard used a high front one. Next, Joan and Jacob both added a high front phoneme to their systems while Hildegard continued to concentrate on the height dimension by adding a mid vowel (/e/). Joan and Jacob both added a mid vowel next but while Joan chose a mid front vowel, Jacob chose a mid back one. This is where the data from Jacob ended. Joan continued on to complete a five vowel system and then began to differentiate between the low vowels. Her vowel system was apparently adult like by 3½ years. Hildegard, once she had established a three level system based on height, began to concentrate on the front/back dimension by adding a high back and then a mid back phoneme. Hildegard’s system was still incomplete at 2 years. Overall, Joan’s and Jacob’s phonemic vowel acquisition were the most similar. These two studies also provided the least data so the similarity may be due to a lack of data.

Unlike, Menn (1976), Velten (1943) does not consider variability (or errors) as an issue and he does not provide much data which indicate that variability was present in Joan’s

---

9 Ingram’s claims actually are supported by the data if they are examined as in my summary paragraph. His error is in the way he has presented the data.
speech. Leopold (1947), on the other hand, does not focus on variability but he does provide information about substitutions. For Hildegard, advancement features were easier to produce correctly than height features. When errors occurred in height, she tended to lower rather than raise vowels. Mid vowels were the least accurate, followed by high and then low vowels. There was no difference in the errors seen in stressed versus unstressed vowels except that unstressed vowels were more often omitted because of the deletion of the whole syllable.

Cross-Sectional Studies

Wellman et al (1931) collected data from 204 children aged 2 to 6 years in a word naming procedure in an attempt to obtain normative data about the ages of mastery of consonants and vowels. Age of mastery was defined as the age at which 75% of the children correctly produced the phoneme. Using this criterion, the following norms were established:

- 2;0 - /i/ /a/ /u/ /o/ /æ/ /ɔ/
- 3;0 - /e/ /ɔ/
- 4;0 - /u/ /e/ /æ/ /ʊ/

Since Wellman’s subjects were all over 2 years, it was not possible to give any order to the acquisition of the earliest phonemes. Irwin and Chen (1943) and Irwin (1948) provided data on children younger than 2 years. These data are phonetic in nature and do not deal with the issue of phonemic acquisition. Instead, they describe trends in the phonetic development of the vowel system. Irwin and Chen (1943) completed a review of the literature on English speech sound development during the first year of life and concluded
that by the age of 6 months, infants are producing most of the vowels.

Irwin (1948) confirmed Irwin and Chen's (1943) conclusion with cross-sectional data on the usage of vowel sounds for a large number of infants and children. Subjects ranged in age from one month to 2 years 6 months and were divided into 15 age levels. The data for each vowel are given as a percentage of total occurrences of vowels at each age level. The purpose of presenting the data in this way was to compare the distribution of vowel sounds at each age level to that of adults. The data showed that for infants aged 1-2 months, most of the vowels produced are transcribed as [e], [i], or [ʌ], although there is evidence of all but [o], [ɔ], and [o] occurring. At the second age level, 3-4 months, all vowel sounds occurred but the distribution was more like that of 1-2 month olds than that of adults. In fact, across all age levels in the first year, most vowels are front or middle vowels. After the first year, there is a gradual change in vowel distribution with the percentage of back vowels increasing until, at two and a half years, the distribution of vowels approximates that of an adult. The gradual change in phonetic distribution which occurs over the first two and a half years can be said to reflect, at least in part, the gradual acquisition of the phonological system. We cannot conclude, however, that Irwin's pattern of data is totally due to phonological acquisition since phonetic distribution will also be affected by the vocabulary used by children and this factor was not controlled for by Irwin.

Irwin and Wong (1983) also provide data on children younger than 2 years from two investigations on children aged 16-18 months (Paschall, 1983) and 21-24 months (Hare,
Each of these investigations looked at 20 subjects and data for each vowel were reported as percent correct in target words. No individual subject data were given. Paschall’s 16-18 month olds had greater than 70% correct for the vowels /a/, /u/, /i/, and /u/, and less than 50% correct for /e/ and /e/ and the rhoticized vowels, /æ/ and /ɔː/\(^{10}\). All other vowels were correct in 50-70% of targeted words. It was suggested that mid vowels may be more difficult to produce than either high or low vowels. Hare’s 21-24 month olds showed a much greater level of accuracy in their vowel production. The vowels /u/, /ʌ/, /ɑː/, /ɔː/, /i/, /æ/, /u/ and /o/ were correct in more than 91% or more of the target words and /e/, /ɛ/, /ɔː/, and /ɪ/ were in the 84-89% correct range. Only the rhotic vowels were correct less than 50% of the time.

Based on their review of the literature on normal vowel development, Stoel-Gammon and Beckett Herrington (1990) suggested that acquisition of English vowels could be divided into 3 groups developmentally: early mastery (corner vowels /ɪ/, /ɑː/, /u/, mid back /o/, and central stressed /ʌ/), mid mastery (/æ/, /u/, /ɔː/ and /ɔː/), and late mastery (front vowels /ɛ/, /ɛ/, /ɪ/ and rhotic vowels /ɔː/ and /ɔː/). Their data from two phonologically disordered subjects, which will be review in a later section, suggests that the order of acquisition of English vowels is relatively similar in normal and disordered subjects. They do, however, state that longitudinal data are necessary to confirm this hypothesis. Again, such longitudinal data are not yet available.

\(^{10}\) The symbol /ɔː/ is used in several studies reported. It is meant to represent the stressed variant of /ɔ/. 
The cross-sectional investigations of vowel acquisition show that, phonetically, children are producing the range of English vowel phones by the age of 3-4 months at the earliest (Irwin, 1948) and 6 months at the latest (Irwin and Chen, 1943). Initially, most phones produced are front or central vowels. Over the first 2½ years, the distribution of phones gradually approaches that seen in adult speech.

Phonemically, the picture is not as clear. Discrepancies between studies may be due to the methods used, the authors’ definitions of acquisition or mastery, or the criteria used to identify a phoneme. All of the studies reviewed reported at least one central vowel ([a] and/or [ə]), a high front vowel ([i] or [ɪ]), a high back vowel ([u] or [ʊ]), and a low vowel ([a] or [æ]) as among the earliest occurring phonemes or most accurately produced vowels. A mid back vowel, [o], was sometimes reported as occurring early with the above-mentioned vowels or a little later. Acquisition or mastery of the mid vowels is inconsistent across studies. Sometimes they are reported as early, sometimes as late. There does not seem to be a pattern across the studies. The rhotic vowels are consistently reported as late-occurring and/or inaccurate. Clearly, there is a need for further research in determining norms for acquisition and mastery of vowel phonemes through cross-sectional (and longitudinal) investigations.

Factors affecting Vowels - rules, variation, and errors

There are three types of phonetic changes that occur in children’s vowels: rules, variation, and errors. Phonetic changes that also occur in the adult system, vowel lengthening...
and nasalization, can be referred to as rules. Phonetic changes that represent minimal fluctuations about a phonemic target are known as variation. Finally, phonetic changes which result in an apparent deviation from the adult form are called errors. I will discuss each of these - rules, variation, and errors.

Locke (1983) discusses the development of vowel nasalization and vowel lengthening in the context of the phonological system. Both processes are presumably phonetic in English. Regressive vowel nasalization is described as a phonetic effect of speakers' anticipation of nasal consonants. Vowel lengthening for English occurs when a vowel precedes a voiced consonant. In both vowel lengthening and vowel nasalization, the phonetic quality of the vowel is affected by the following consonant, a regressive process. Although they are phonetic in adult form, changes in vowel length and nasalization have the potential of becoming phonemic, as they have in other languages, and, therefore, they must be examined carefully in developing speech.

Phonetic changes which represent variation about a target are also important to observe in developing speech. Local (1983) presented data from a child, Paul, at the ages of 4;5, 5;0, and 5;6. The purpose of this short paper was to show the importance of studying phonetic variation in children’s speech as a means of discovering the way in which they acquire the phonological system. Local pointed out that research on the development of the phonological system tends to ignore phonetic variation in favour of supporting what he calls "simplistic phonological theories". His analysis of the phonetic variation found in Paul’s production of
the phoneme /i/ showed that phonetic variation can be phonetically or phonologically conditioned or neither and that the range of phonetic variation decreases with development conforming more and more to the variation seen in the ambient language. Local's point is valid - when studying phonological development we must take phonetic variation into account. It is interesting to note the age of Local's subject, 4;5-5;6. By attending to the variation in Paul's speech, Local showed that the child's system may not be adult-like as early as is assumed by other researchers.

Vowel errors, like phonetic variation, can tell us much about the process of acquisition. In their discussion of commonly occurring phonological errors, Stoel-Gammon and Dunn (1985) include three processes which involve vowels: neutralization, vocalization, and epentheses. Neutralization of a vowel refers to a loss of vowel quality, usually resulting in [ə]. The substitution of a vowel, usually [o] or [u], for syllabic and/or syllable-final nasals and liquids is referred to as vocalization. Epentheses is the insertion of an unstressed vowel, usually [ə], either within a consonant cluster or at the end of a word. These error patterns are reportedly frequent in the speech of young children.

Ingram (1976) discusses the types of phonological processes\(^{11}\) that affect vowels in normally developing children. He gives examples from previous research which looked at the processes of assimilation and simplification. Assimilation processes, regressive and

\(^{11}\) The term "process" is used throughout this thesis as a descriptive tool not as an explanation of phonological change.
progressive, occur for both adjacent (contiguous) and non-adjacent (non-contiguous) segments. Regressive contiguous assimilation occurs when the vowel in a CV sequence influences the preceding consonant\(^{12}\) or when the consonant in a VC sequence influences the preceding vowel\(^{13}\). Progressive contiguous assimilation occurs when the vowel in a CV sequence is affected by the preceding consonant\(^{14}\) when the consonant in a VC sequence is affected by the preceding vowel\(^{15}\). Non-contiguous assimilation, or vowel harmony, can also be either regressive or progressive. Ingram also gives examples of simplification processes which, for vowels, is said to be neutralization\(^{16}\). Both assimilation and simplification have strong coarticulatory roots.

Bleile (1989) examined the development of vowels in two normally developing children, aged 1;10 and 2;0 at the start of the study. The purpose of the investigation was to identify and analyse vowel error patterns that had not previously been reported as widespread among typical children. Bleile therefore excluded neutralization, vocalization, and epenthesis. He then identified four vowel patterns seen in the diary studies of Leopold

---

\(^{12}\) Smith (1973) gives an example of a process whereby /n,t,d/ became /ŋ,k,ɡ/ when followed by /u/ where /u/ was a substitute for syllabic /l/.

\(^{13}\) For example, vowel lengthening or nasalization as discussed by Locke (1983)

\(^{14}\) Leopold (1947) gives an example of lip rounding spreading from a /b/ forward to change /i/ to /u/\(^{15}\)

\(^{15}\) Leopold (1947) gives an example of /p/ becoming /k/ when preceded by /o/.

\(^{16}\) The results of some studies reviewed later indicate that there may be other types of simplification processes that affect vowels.
(1947), Menn (1976), and Smith (1973): diphthong reduction (reduction of diphthongs to monophthongs), height changes (primarily raising of front vowels), low vowel neutralization (decreasing or eliminating contrasts between low monophthongs and/or diphthongs), and [ai] patterns (a number of diverse patterns in which [ai] is the favoured substitute). In his investigation, he was looking for further evidence of the above-mentioned patterns in typical children's speech as well as evidence of other patterns not previously mentioned.

Each child was observed at home three times a week for eight weeks. Data were collected during play, reading, and snack time. Both children produced the full range of English vowels, with the exception of r-coloured vowels, and both exhibited errors that were not previously reported as widespread. The first pattern, referred to as the [ai] pattern, was exhibited only by the youngest child, Kylie. The [ai] pattern optionally changed [ei], [æ], and [ar] to [ai]. The pattern applied to [æ] substantially more frequently. The second pattern is referred to as resyllabification and it was exhibited by both children. Kylie optionally added [wa] to words ending in [au] thus creating another syllable. Jake, the older child, optionally added a syllable to words ending in both [au] and [ɔɪ]. Jake’s pattern for [au] was the same as Kylie’s but for words ending in [ɔɪ], he only added [ɔ]. The third pattern identified was vowel lowering and it was exhibited only by Jake. Vowel lowering optionally changed [i] to [ɛ] in about half of the words where lowering was possible. Bleile concluded that his subjects, approximately 2 years of age, both evidenced vowel patterns that were similar to some previous descriptions found in case studies.
Bleile did indeed find some patterns that are globally similar to previously reported error patterns but the more important finding is that his data are not exactly like previous reports. The [ai] pattern exhibited by Kylie is similar to previous reports in that [ai] is the substitute but, more importantly, the rule applies to different phonemes. Resyllabification was not seen in the diary studies Bleile reviewed and it was different for each of the two children. Finally, Bleile identified height changes in the speech of Jake but unlike those seen in the diary studies, Jake lowered the front vowel /i/ to [e] rather than raising it to [i]. What is significant about Bleile's findings is not that they are globally similar to some other observed vowel errors, but that they differ in many ways. It would appear that a variety of errors in vowel production do occur in the normally developing population but, for some reason, they have not been observed.

In sum, there are a number of diverse factors that affect children's production of vowels: phonetic rules which are not phonemic in English but have the potential of becoming so in children's speech; phonetic variation which may or may not be rule-governed and which sometimes indicates impending change in the child's system; and vowel errors which are more diverse and, perhaps, more common, than previously thought.

Summary

The existing data on phonological vowel development has been reviewed and the primary conclusion that can be drawn is that the findings are diverse. Phonetically, children are able to produce the range of English phones at an early age, 6 months at the latest, but
the distribution of vowels types is not adult-like until about 2½ years. Phonetic variation has been shown to be an important characteristic of children’s vowel production which warrants further attention. Phonemically, the course of vowel development is still unclear. Both cross-sectional and diary studies have shown that children may acquire vowels at the extremes of the vowel space before adding mid vowels, although /o/ is sometimes reported as an early-appearing phoneme. Beyond this point, it is not clear whether or not children follow a predictable course of development since the data do not converge. The number of different error patterns identified in various studies is astounding, given the fact that it is a commonly held belief that vowels are accurately produced relatively early. Clearly, there is a need for further research in the area of the normal development of vowels. A large group longitudinal study would certainly fill this gap.

3.2 Acoustic Phonetic Studies: Normal Development

The earliest acoustic data from children’s vowel production comes from Peterson and Barney’s (1952) study of the relationship between the perception of vowels and their acoustic characteristics. In addition to two groups of adults (one male and one female), subjects included fifteen children of unspecified age and gender. Each subject read two lists, of ten words each, in randomized order. Presumably, the children were old enough to perform this task. All words were of the form /hVd/, where V was one of 10 different vowels.

Listeners heard the words over a loudspeaker and were asked to classify each word as
one of the ten possibilities. Results are presented as the number of times (out of a possible 152) that listeners unanimously classified the vowel as that intended by the speaker. Vowels were never unanimously classified as something other than what the speaker intended. The vowels [i], [ɜ'], [æ], and [u] were correctly classified most often and classification of [i], [ɜ], and [u] was most resistant to practice effects. When a vowel was misclassified, listeners almost always chose a vowel adjacent to the intended vowel in a formant frequency plot (F1 x F2).

Sound spectrograms were made of each word and the steady state portion of each vowel was identified. The steady state was defined as "a part of the vowel following the influence of the [h] and preceding the influence of the [d] during which a practically steady state is reached" (op. cit., p. 177). The frequencies of formants one to three (F1, F2, and F3) and the fundamental (f₀) were estimated from amplitude sections at the steady state portion of the vowel. Results showed that the frequencies of f₀, F1, F2, and F3 were highest for children's vowels, lowest for adult males', and intermediate for adult females'. Although repetitions of the vowels by one of the experimenters defined isolated vowel areas with no overlap on a scattergram (F2 versus F1), combined data from all subjects showed considerable overlap, partly, but not wholly, due to differences between men, women, and children. Peterson and Barney further demonstrated that even when only those vowels which were unanimously classified by listeners were included, the vowel areas still overlapped due to between subject variation. Peterson and Barney concluded that formant measurements from a single amplitude section were too simplistic to accurately reflect the complex
acoustical patterns of the words produced. Nevertheless, research involving formant measurement in vowels has continued.

Eguchi and Hirsh (1969) report cross-sectional data for \( f_0 \), F1 and F2 of children’s vowels. Their subject group consisted of 84 children aged 3 to 13 years. Children ten years of age and under were divided into eight age groups one year apart, each containing 5 or 6 children. Children over 10 years of age were divided by age and gender giving 6 more groups of 5 or 6 subjects each. There were also two groups of adults, one male and one female. Subjects were recorded repeating two sentences five times each. Subjects 7 years and under imitated the test sentences spoken by a native American speaker while those over 7 years of age read the test sentences from a card.

Formant frequencies (F1 and F2) of each of 6 vowels were estimated from spectral envelopes drawn on expanded narrow band sections at the vowel’s steady state. Results showed that as age increased, F2 values tended to decrease more than F1 values, especially from 3 to 5 years. An exception was the F1 value of [a] which appeared to be relatively stable and independent of age. Between subject standard deviation of formant frequencies was not dependent on age whereas intra-subject standard deviation decreased as age increased. For F1, the greatest intra-subject variability was seen for [a] and the least for [i] and [u]. This result is explained in part by the fact that absolute F1 values are lower for [i] and [u] than for [a]. Intra-subject standard deviation for F2 also decreased with increases in age but did not depend on the vowel.
In the same study, fundamental frequency was estimated by counting the number of harmonics present in the signal up to 4000 Hz. The fundamental frequency data are given only as an average over all vowels. The results showed that fundamental frequency decreased with increases in age, and the largest decrease occurred between 3 and 6 years of age. Between subject standard deviation ranged from 20 to 45 Hz. across age groups and was not related to age. Intra-subject standard deviation decreased gradually with increases in age.

Eguchi and Hirsh also performed listening tests with their data using a forced choice procedure (i.e. subjects chose from a closed set of vowels). The results showed that vowels became easier to identify as speaker age increased. This result may have been due to the decrease in intra-subject variability seen in the acoustic measures reported above. It was also found that [i] and [u] are easiest to identify and [a] is the most difficult. This result may be related to the previously mentioned finding that intra-subject variability of F1 was highest for [a] and lowest for [i] and [u].

Gilbert (1973) examined the vowel production of children aged 1;2 to 7;0 in free verbalization. The children were grouped both by chronological age and by bone age, a measure of physiological maturity measured from X-rays. The formant frequencies of five repetitions of each of four vowels (/i/, /æ/, /a/, and /u/) were measured from wide band spectrograms. It was hypothesized that bone age might prove better than chronological age in grouping children to compare their vowel productions. However, the same pattern of results was seen for bone age groupings as for chronological age groupings. Specifically, the
values of F1 and F2 decreased as chronological age or bone age increased.

Data from a longitudinal, cross-sectional acoustic study of children's developing speech are presented by Lieberman (1980). The data reported were from a large corpus of recordings of infants and children who ranged from 16 weeks to 5 years at the beginning of the study, although only data from children under 3 years are reported. Recordings were made in the home at weekly or two week intervals. Spectrograms were made with 90 Hz and 600 Hz bandwidths and formant values (F1, F2, and F3) were measured at the steady state of each vowel. Formant values were estimated from spectrograms and some were checked with Fourier analysis and linear predictive analysis. Approximately 50% of the data was discarded because of difficulty reading the spectrogram, usually due to a high fundamental frequency.

The results showed that, in individual children, the acoustic vowel space, that is, the space defined by an F2 versus F1 plot, gradually became more well-defined as the age of the child increased. This result supports the findings of Eguchi and Hirsh (1969) in a subject group younger than those tested by Eguchi and Hirsh. Lieberman found that the 'perfection' of the acoustic vowel space, that is, development of well-defined, minimally overlapping acoustic space for each vowel, occurred during babbling and continued well into the period of phonological acquisition. On the other hand, phonological studies, which use phonetic transcription rather than acoustic analysis, have demonstrated that vowels are accurately produced early in the phonological acquisition process. This discrepancy between findings
is possibly due to the different methodologies used in phonological and acoustic phonetic studies. That is, acoustic measurements are more sensitive to slight changes in articulation than phonetic transcription; as a result, acoustic studies tend to show developmental changes in vowel production which are not seen in phonological studies.

Consistent with previous research, Lieberman found that formant values of vowels produced by infants and children are neither identical to nor linearly related to formant values of adults vowels. Instead, the formant values of children’s productions of [i], [u], and [a], which are produced with the articulators in extreme positions, define the corners of the acoustic vowel space: all other vowels are produced within this space. Lieberman points out that, although children are physiologically capable of reproducing the absolute adult formant values for [i], [ɛ], and [ɛ], they do not. Instead, they maintain the relationships between vowels in the acoustic, and articulatory, vowel space which exist in adult productions. Lieberman interpreted his findings as support for a normalization function in perception which is relative to the size of the vocal tract.

Bennett (1981) examined vowel production of 42 children in a study which looked for sex differences between males and females at 7 and 8 years of age. Six vowels (/i/, /u/, /æ/, /u/, and /ʌ/) were elicited in a [dVd] word within a carrier phrase. Five phonetically trained listeners transcribed the vowels from a field of choice of 8 vowels and only those vowels for which four of the listeners agreed on the correct vowel were chosen for analysis. Formants 1 to 4 were measured directly from wide band spectrograms (300 and 450 Hz.). Each
subject's mean formant values were calculated from at least two repetitions of each vowel with the exception of /u/ which was eliminated from the analysis because F3 and F4 were often poorly defined and F2 changed throughout the vowel. Bennett found that the mean formant values were lower in males than in females and that the amount of difference depended on the formant and the vowel. She also correlated her results with several measures of body size and found that the sex differences in acoustic measures were primarily due to differences in body size.

Selected results from the above mentioned studies are presented in Table 3.1. The picture to emerge from these acoustic studies shows that children's vowel formant frequencies are higher than those of adults but not linearly related to adult formant frequencies. Developmentally, formant values decrease in absolute value and are more consistently produced by individuals resulting in a decrease in intra-subject variability. Error of measurement, defined as one quarter of the fundamental frequency by Lindblom (1962), necessarily decreases with the developmental lowering of children's fundamental frequencies and may account, at least in part, for the decrease in variability. Vowels are more easily identified by listeners as a speaker's age increases, possibly due to more consistent production. Also, sex differences in formant frequency data appear as early as seven years of age in samples from normal children.
Table 3.1 Selected results from acoustic studies of children’s vowel production.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C.A. = 6 yrs.</td>
<td>C.A. = 6 yrs.</td>
<td>C.A. = 7-8 yrs.</td>
</tr>
<tr>
<td>/i/</td>
<td>F1 ̅x</td>
<td>397</td>
<td>440</td>
</tr>
<tr>
<td></td>
<td>sd*</td>
<td>15.2</td>
<td>40.0</td>
</tr>
<tr>
<td>/ε/</td>
<td>F1 ̅x</td>
<td>3108</td>
<td>3276</td>
</tr>
<tr>
<td></td>
<td>sd</td>
<td>210.3</td>
<td>228.7</td>
</tr>
<tr>
<td>/æ/</td>
<td>F1 ̅x</td>
<td>512</td>
<td>642</td>
</tr>
<tr>
<td></td>
<td>sd*</td>
<td>61.1</td>
<td>52.17</td>
</tr>
<tr>
<td>/u/</td>
<td>F1 ̅x</td>
<td>611</td>
<td>1192</td>
</tr>
<tr>
<td></td>
<td>sd*</td>
<td>98.5</td>
<td>129.5</td>
</tr>
<tr>
<td>/ɔ/</td>
<td>F1 ̅x</td>
<td>431</td>
<td>528</td>
</tr>
<tr>
<td></td>
<td>sd*</td>
<td>28.6</td>
<td>335.4</td>
</tr>
<tr>
<td>/α,a/</td>
<td>F1 ̅x</td>
<td>809</td>
<td>1256</td>
</tr>
<tr>
<td></td>
<td>sd*</td>
<td>109.1</td>
<td>79.3</td>
</tr>
<tr>
<td></td>
<td>F2 ̅x</td>
<td>1655</td>
<td>1792</td>
</tr>
<tr>
<td></td>
<td>sd*</td>
<td>63.3</td>
<td>233.9</td>
</tr>
</tbody>
</table>

* between-subject standard deviation

Kent (1978) and Kent and Forner (1979) present a different picture of the relationship between the vowels of adults and children. Their cross-sectional data, from a synthesized vowel imitation task, demonstrates that there may indeed be a linear relationship between the formant frequencies of adults and children. Preschool aged children (Kent, 1978) and 4, 6, and 12 year old children, and adult males and females (Kent and Forner, 1979) were asked...
to imitate synthesized 5 formant vowels with F4 and F5 fixed at 3500 and 4500 Hz. Five of the vowels were synthesized to match adult productions of real English vowels and the others were arbitrary vowels. Spectrograms were made with 45, 300, and 500 Hz bandwidth filters and formants one to three were measured directly from the spectrograms. Some formant measurements were checked with linear predictive analysis. The results showed that when formant frequency data were plotted with F1 and F2 axes linearly scaled in a 1:2 ratio, formant values fell along approximate isovowel lines passing through the origin. The scale factors relating men’s, women’s, and children’s formant values were found to vary with the vowel.

Summary

In general, the acoustic studies of children’s vowel production are consistent. Fundamental frequency and formant frequencies are higher and more variable in children’s vowels than adults’. As children grow, their speech mechanism (the vocal tract and the larynx) approaches the size and shape of adults’ resulting in more adult-like fundamental and formant frequencies. As early as 7 years, there may be acoustic differences in the vowel production of males versus females. In addition to decreases in absolute frequency values, the intra-subject variability of acoustic measurements decreases with development. This may be due to improving articulatory control, decreasing measurement error, or both. Interestingly, inter-subject variability does not appear to change across development. This finding might suggest that decreases in intra-subject variability are due more to the improved articulatory control of individuals than to decreases in measurement error which should apply
equally to all subjects and result in decreases in inter-subject variability.

Inconsistency in the developmental acoustic literature lies in the hypotheses surrounding the relationship between acoustic measurements of children’s and adults’ speech. Lieberman (1980) suggested that there is not a linear relationship between the formant frequencies of children and adults whereas Kent and his colleagues (1978, 1979) have suggested the opposite. They plotted their data with F1 and F2 axes linearly scaled in a 1:2 ratio and found that a linear relationship, dependent upon the vowel, did exist. Lieberman (1980) used the same scale to plot his data but failed to see a linear relationship. There are several possible reasons for this discrepancy. Lieberman’s child subjects were between the ages of 16 weeks and 3 years whereas Kent’s subjects ranged from 3;11 to 12 years. Lieberman’s data were collected in the home during free verbalization whereas Kent’s data were gathered in a clinical environment using an imitation task. Lieberman was not specifically looking for a linear relationship while Kent was. Whatever the reason, the specific relationship between acoustic measurements of children’s and adult’s vowel production remains unclear.
4. Children’s Vowel Production: Atypical Development

Published research on the vowel production of atypical populations is also limited and diverse. Phonological studies of atypical vowel production from phonologically disordered populations are rare. Researchers have done acoustic phonetic studies of special populations such as Down’s Syndrome, hearing-impaired, or language delayed children but have almost ignored the phonologically disordered population. Research examining the effects of intervention on vowels comes only from studies of the hearing impaired population. The literature in these three areas is reviewed below.

4.1 Phonological Studies: Atypical Development

Ingram (1976) reviews several diary studies of language delayed and phonologically disordered children. Hinkley (1915) reported on a language delayed child, Ethel, whose vowels at the 50 word stage, he said, were more advanced than normal. His transcription showed that vowels are like the adult form in stressed syllables but are restricted in unstressed syllables. That is, they were totally predictable. If the syllable was reduplicated, the vowel was [i], all other vowels in unstressed syllables were [a]. Lorentz (1974) reported a subject, David, whose vowels and nasals were the only phonemes produced without error. Ingram also reports on some phonological studies of special populations. Bangs (1942) demonstrated the presence of the vocalization process of the phoneme /r/ in the mentally retarded population. Hudgins (1934) described the characteristics of deaf speech as including
prolonged productions of vowels leading to the distortion or creation of a new syllable and excessive nasality in vowels and consonants. Hudgins and Numbers (1942) identified 5 vowel error types in the hearing-impaired population. Substitutions accounted for the majority of vowel errors. Other error types included diphthong distortions (either the creation of two syllables by insertion of a glide or the reduction of the diphthong to one vowel), creation of two syllables (without the presence of a diphthong), vowel neutralization, and vowel nasalization. Not all of these patterns are seen in all hearing-impaired speakers, but this number of vowel errors in any one group is unusual. The phonology of two Down’s Syndrome children was reported by Bodine (1974). For one child, vowels were not mentioned. For the other, vowels were reported to have been a better aspect of his phonology but still showed some degree of instability.

Hargrove (1982) described a child, Vic, 4 years 7 months of age, who demonstrated consonant and vowel errors and unusual prosody which rendered him quite unintelligible. He had no hearing loss, structural inadequacy, or dysarthria. 100 utterances were analysed. Vic had a full phonetic inventory of vowels except for the rhotic vowels, /ɔ/ and /ɔ'/. However, almost 40% of Vic’s vowel productions were phonologically incorrect. Tense vowels /i/, /e/, /o/, and /u/ were usually correct but nontense and neutral (central) vowels were frequently misarticulated. Front vowels were correct 81% of the time, back vowels 69% and central vowels only 19%. High vowels were correct 85% of the time, low vowels 60% and mid vowels 51%. In multisyllabic words, Vic’s vowels were correct only 29% of the time whereas in single syllable words, they were correct 77% of the time. Vic’s vowel
substitution patterns were inconsistent but, nevertheless, for each phoneme a predominant substitution could usually be identified. Hargrove identified seven patterns in Vic's vowel production errors, all of which were optional. They were as follows:

1. Raising of low, nontense vowels: This pattern accounted for 82% of the errors which affected /a/ (--> [o]) and /æ/ (--> [e]) and did not appear to be related to phonetic context.

2. Tensing of /e/ resulting in [e]: This pattern occurred in 75% of words with two vowels where the second vowel was tense (vowel harmony). Tensing of /e/ also occurred when /e/ had been derived from another vowel (50% of the time). No other structural description was required for this second type of tensing.

3. Lowering of /e/ resulting in [æ]: When /e/ was derived from another vowel and the phonetic context included two or more consonants, at least one of which was a nasal or a /p/, /e/ was changed to [æ].

4. Changes in /ʌ/: 39% of /ʌ/ errors are [e] substitutions. This substitution occurred mostly in the environment of /s/, /w/, or no consonants. The [e] substitution appears to be the primary pattern for /ʌ/ because the other two substitutions, [æ] and [e], can be derived from /e/ using patterns #2 and #3 above. The [æ] and [e] accounted for 29% and 22% of /ʌ/ errors respectively.

5. Changing /s/' and /z/ to pure vowels: This is a vocalization rule that resulted in either [u], [o], or [u] substitutes for the rhotic vowels 100% of the time.

6. Lower tense vowels: Although tense vowels were usually correct, there were a few errors resulting from lowering. They did not occur in a predictable phonetic context.
7. Vowel harmony: As mentioned in pattern #2, Vic harmonized vowel tenseness. An analysis of his multisyllabic word production indicated that 71% of word forms had either all tense or all nontense vowels. Only 33% of the word forms would have had all tense or all nontense vowels if they had been correctly produced.

Hargrove concluded that reports of misarticulated vowels are rare either because consonant problems were considered more serious by clinicians and/or the rarity of the problem. She did not give any longitudinal data on Vic or any intervention information.

Stoel-Gammon and Beckett Herrington (1990) hypothesized, on the basis of a literature review, that two groups of children exist who show disorders of the vowel system. The first group consists of children who have large vowel repertoires but exhibit many errors. The errors primarily occur in the mid vowels, high lax vowels, and rhotic vowels. The second group is described as similar to prelinguistic infants in that the vowel inventory consists of two or three lax vowels with many errors in the tense vowels.

In a preliminary attempt to investigate their hypothesis, Stoel-Gammon and Beckett Herrington presented case studies of two phonologically disordered girls, aged 3;8 and 4;2, who showed vowel errors. Both girls had normal hearing, cognition, and oral-motor structure and function, and intelligibility less than 20% when context was unknown. Single words and short phrases were elicited for analysis. For each subject, an inventory of vowel phones, correct productions, and error patterns were given. Effects of word length, phonetic context,
and stress were considered.

The results for the first subject, G1, showed greater accuracy for back than front vowels and greater accuracy for front than central vowels. Three groups of vowels emerged: 1) those that were correct 100% of the time (/i/, /u/, /o/, and /a/); 2) those that were present but correct only 18-31% of the time (/e/, /æ/, /ʌ/, and /ʌ/); and 3) those that were absent from the inventory (/e/, /u/, /ɔ/, /ɔ/, and /ə/). Vowels in the first group served as substitutes for the vowels in groups 2 and 3.

Three basic substitution patterns were described for G1: tensing (/i/-->/i), raising/backing (/u, /ʌ'-->/u), and lowering/backing (/æ, e, e, A-->/a). The most variable vowel was /e/ which surfaced as [ʌ], [æ], [a], [æ], and [o], although [a] was the most frequent. In general, G1’s vowels were more accurate in monosyllables or stressed syllables of multisyllabic words.

The results for G2 were not as straightforward. There were no clear patterns of accuracy such as high versus low or front versus back as there were for G1. Stress, however, seemed to have an effect on accuracy since, in general, stressed vowels were more accurate than unstressed ones. Three groups are also described: those that were 100% correct (/i, æ, o/), those that ranged in accuracy from 60% to 83% correct (/ʌ, u, a, e/), and those that were
almost always incorrect (/ɪ, ɛ, u, ə, ɔ, æ/)\(^1\). There was a general pattern of lowering non-high front vowels to [æ]. However, /e/ was raised to [i] when it was followed by a nasal + a voiceless consonant (eg. /tent/ → [tint]). /l/ was raised to [i] except in the word "sink" where it was lowered to [e]. Of the back vowels, /o/ was the most accurate (100%), followed by /a/ and /u/ (both 75%), and /u/ was never correct, although it was only targeted twice. Of the central vowels, /ʌ/ was the only phoneme that was ever correct (83%). Errors (→ [æ]) occurred only in multisyllabic words. The rhotic vowels were substituted by [u] once and [o] the rest of the time. Unstressed /ə/ was subject to vowel harmony in three-syllable words and was substituted by [i] otherwise.

There are both similarities and differences in the vowel systems of the two subjects. The phonetic inventories of vowels for the two girls are the same. Although, their 'always correct' groups both contain /ɪ/, a low vowel (/a/ or /æ/) and at least one back rounded vowel (/o/ and /u/), their intermediate groups differ. For G1, the vowels in this category were only occasionally correct (18-31% accuracy). For G2, the phoneme /l/ falls in the 'occasionally correct' range but the rest of her intermediate vowels are 'mostly correct' (60-83%). Overall, G2's vowels were more accurate than G1's (47% versus 38%), yet her error patterns are more difficult to explain. Both subjects produced /i/ and /o/ correctly 100% of the time. Unstressed vowels, especially /ə/ and /l/, were difficult for both subjects. For both subjects, the vowels in group 1 served as the primary substitutes for other vowels.

\(^1\) Why /l/ is not included in the second group is unclear, since it is the only phoneme in group 3 which is ever correct (21%). In this way, the three groups for G1 and G2 would be comparable with the third group being those phones which are absent from the inventory.
Stoel-Gammon and Beckett Herrington then looked at the similarities and differences between the normal population and the phonologically disordered population. They noted that vowel accuracy in phonologically disordered subjects, with large vowel inventories and a high proportion of vowel errors, roughly parallels the order of acquisition of vowels seen in younger normal subjects from which they derive a cautious hypothesis; that is, the order of acquisition in the two groups is the same. Longitudinal data from phonologically disordered subjects is, however, needed to confirm the hypothesis. The major difference between normal data and disordered data was the low accuracy of the central vowels /ʌ/ and /ɔ/ in the disordered population. They suggest that this is because of the combined effects of vowel quality and stress patterns.

In general, it appears that normal and phonologically disordered children may acquire vowels in similar sequences. Vowels at the extremes of the vowel space, point or corner vowels, are acquired early. Gradually the vowel system fills out. One discrepancy between typical and disordered vowel acquisition is the production of unstressed vowels. Whereas vowel reduction (a neutralization of vowel quality in an unstressed environment) appears to be common in the vowel production of normally developing children, disordered children have difficulty with vowels in unstressed syllables: lax vowels, which usually occur in unstressed syllables, are frequently tensed.

Pollock and Keiser (1990) surveyed the speech of 15 phonologically disordered subjects aged 3;8 to 6;4 for the presence of vowel errors. All subjects passed a pure-tone audiometric
screening test and were rated either moderate, severe, or profound on the Computer Assessment of Phonological Processes (Hodson, 1985). Information about receptive and expressive language, middle ear infections, and oral mechanism was gathered for each subject but they did not control for these factors. The data for each subject included at least four targeted productions of each vowel and diphthong. Data were gathered for both monosyllabic and multisyllabic words.

The results indicated that one of the fifteen subjects had a severe problem with vowel articulation and seven or eight had mild to moderate vowel problems. Fourteen of the fifteen subjects produced the rhotic vowels correctly less than 75% of the time. The rhotic vowels most frequently appeared as [ʌ]/[ɔ], [ɒ]/[ɔ], depending on stress, or [u]. The non-rhotic vowels most frequently in error were /au/, /æ/, and /u/ and those most frequently correct were /i/, /u/, and /o/. The finding that /i/ and /u/ are more frequently correct than /æ/ and /u/ is consistent with the literature on normal vowel development which suggests that the point or corner vowels are acquired earlier. Pollock and Keiser identified many error patterns seen in the no-rhotic vowel production of their phonologically disordered subjects. They did not account for the effect of consonantal context. The error patterns fell into three general categories: feature changing errors\(^2\) (76% of the total errors), complexity changing errors (28% of the total), and vowel harmonies (3% of errors). They were strict in their definition of vowel harmony and state that if they had not been, vowel harmony would still have

\(^2\) The feature changing errors identified were backing, fronting, lowering, raising, centralization, tensing, laxing, rounding, and unrounding.
accounted for only about 9% of the total errors. Of the feature changing errors, backing and lowering accounted for the majority of the errors (67%). Backing most frequently affected /æ/ resulting in [a] or [a] and when other front or central vowels were backed, they were usually lowered as well, resulting in [a]. Lowering most commonly affected front vowels although it did affect the back vowels for some subjects. Complexity changing errors included diphthongization and diphthong reduction. Of these, diphthong reduction accounted for the majority of the complexity changes (68%). Diphthong reduction was seen for all diphthongs but it most commonly affected /au/. Pollock and Keiser concluded that their data were consistent, in general, with some previous findings. They point to the need for studies of more homogeneous groups and the use of alternative techniques, such as instrumental/acoustic analysis, to confirm results based on perceptual transcription.

Reynolds (1990) surveyed the speech of 20 children with phonological disorders who showed vowel errors in an effort to identify the types of vowel errors that occur. He summarized the local system of vowels (a dialect of British English) and then described the types of errors that he found. There were instances of vowel errors for all phonemes with the exception of /a:/ (as in "farm") and /a/ was less prone to error than other vowel phonemes. Reynolds stated that this shows support for the Jakobsonian /p/-/a/ contrast which is hypothesized to be the first contrast that children acquire. In making this statement, however, Reynolds assumed that /a/ is less prone to error because it has been in the vowel

---

3 Reynolds refers the reader to his unpublished PhD. dissertation for details about data collection and transcription.
system for longer. Longitudinal data is required to show the appearance of /a/ as the child’s first vowel. Overall, the most frequently affected vowels were the mid-front vowels /e, e:, eI/, diphthongs and triphthongs, and the stressed central vowel /ə/. High vowels, low back vowels, and unstressed vowels were less frequently affected. Reynolds identified context-free process, context-sensitive processes, and idiosyncratic processes which occurred in the data.

Context-free processes included lowering, fronting, diphthong reduction, and a general preference for peripheral over central vowels. Lowering typically affected the mid front vowels changing /e/ to /a/ in the short, long, and diphthongized mid front phonemes. High-front vowels were also sometimes affected by lowering, although this was infrequent. Fronting applied most often to low back vowels changing /o, u, u/ to /a, a:, a/. Fronting applied less frequently in u-diphthongs changing /u/ to /i/. Diphthong reduction usually consisted of the loss of the off-glide sometimes with a compensatory lengthening of the nuclear vowel. The central vowel /ə:/ was usually realized as /a:/ but sometimes it appeared as a back vowel or a high front vowel. Since the surface variant was not predictable by context, the treatment of central vowels was considered simply a preference for peripheral over central vowels.

Reynolds suggested that the context-free processes be considered natural trends towards simplification of the vowel system. He examined each in terms of its naturalness. Lowering, he suggested, can be seen as a tendency towards a more open vowel. For vowels, this is a natural process parallel to stopping in the consonant system. Since the earliest vowels in a
child's repertoire are fully open and consonants are fully closed, later development must involve increasing control over the degree of aperture. Thus lowering of vowels (and stopping of consonants) can be seen as a trend toward a more simple articulation. He also gives a perceptual argument for the tendency towards more open vowels. Open vowels are more perceptually salient because of their greater sonorance and will, therefore, be preferred. There are no similar perceptual and articulatory arguments for the naturalness of fronting. As with lowering, however, Reynolds presented a parallel in the consonant system. It is well documented that phonologically developing children show a preference for front consonants, although backing does occur as well. Reynolds argued that if this naturally occurs for consonants, it may naturally occur for vowels. Diphthong reduction can be seen as a simplification process that is similar to cluster reduction in the consonant system. By reducing complex vowels to simple ones, children are maximizing the simple CV pattern which occurs early in their speech. Reynolds stated that the preference for peripheral over central vowels may occur because of the late appearance of /ə:/ in the speech of children in general but he gave no supporting evidence. It may, in fact, be the least natural of the context-free processes.

Reynolds rarely observed context-sensitive processes. He only described two - lowering/backing of vowels when followed by a "dark l", and the tendency towards a more open vowel when a vowel is followed by a nasal. The first of these is an assimilation processes whereby the vowel assimilates to the velar quality of the "dark l". The second process results from the perception of a nasalized vowel as being more open. In an attempt
to recreate the vowel heard in the environment, the child produces a more open vowel rather than a nasalized one. Reynolds noted that both processes have been observed in the speech of normally developing children although they appear to be applied more frequently by phonologically disordered children.

Idiosyncratic processes are said to be either those which stand out as deviant within the child’s system (for example, a child who continues to exhibit vowel errors after the disorder of his consonant system has been resolved) or those that occur as the result of a system which is qualitatively different from the adult system and not just a scaled down version of it. Reynolds presented several cases of children who showed idiosyncratic processes, such as fronting of high back vowels to /y/ or /u/ or a preference for triphthongs, but I shall not discuss these in detail.

The longitudinal changes seen in Reynolds’ subjects suggest that whereas some children resolve idiosyncratic processes first, others may produce more consistent error patterns so that a more stable system is achieved. The data also suggest that some phonologically disordered children may be less able to use variability to move forward in phonological development (see discussion of Menn, 1976). That is, whereas and increase in variability in normally developing children is often a signal to impending phonological change, the same increase in variability in the speech of a phonologically disordered child may not lead to change.
Summary

Prior to Hargrove's (1982) report of Vic, data on the status of vowels in phonological disorders was scarce. While the literature on deaf speech provided some detail on vowel production, there was very little information from studies of other types of speech disorders. Each of the four studies reviewed contributes to the literature in a different way. Hargrove (1982) was the first study to focus specifically on vowels and, in addition to a complete description of Vic's disordered vowel system, she provided the impetus for further research into disorders of the vowel system. She did not provide any longitudinal data.

Stoel-Gammon and Beckett Herrington (1990) provided two case studies and attempted to draw some general conclusions about the types of disordered vowel systems that exist. They hypothesized the existence of two groups of children with disordered vowel systems: those with large inventories and a high percentage of vowel errors and those with small inventories of mostly lax vowels, similar to prelinguistic children. Both of their subjects fell into the first group. They also found that, at least for their subjects, vowel accuracy rates appear to parallel order of acquisition in younger normal children, with the exception of the central vowels which were much less accurate in the disordered children's speech. Like Hargrove, Stoel-Gammon and Beckett Herrington did not provide any longitudinal data.

Pollock and Keiser (1990) and Reynolds (1990) each surveyed the speech of large groups of phonologically disordered children in order to identify error patterns seen in vowels. Pollock and Keiser identified many error patterns which fell into three categories:
feature changing patterns (primarily lowering and backing), complexity changing patterns (primarily diphthong reduction), and vowel harmony patterns, which were infrequent. They did not, however, consider the effect of consonantal context and did not provide any longitudinal data. Reynolds identified context-sensitive, context-free, and idiosyncratic processes in his data. Context-sensitive processes rarely occurred and idiosyncratic processes, by definition, were different for different children. Context-free processes are considered to be processes of simplification of vowels: lowering, fronting (a finding contrary to Pollock and Keiser), diphthong reduction, and a general preference for peripheral over central vowels. Reynolds’ classification of these processes as simplification challenges researchers to reconsider the common conception of simplification as neutralization (substitution by /æ/).

Reynolds did make some general comments regarding longitudinal observations of his subjects. He stated that there was no predictable order of resolution of vowel errors and that variability in vowel production may not serve the same function (to signal, or perhaps facilitate, change) in phonologically disordered children’s speech as it does in the normal population.

4.2 Acoustic Phonetic Studies: Atypical Development

Studies which have used acoustic measures to examine atypical vowel development have focused on hearing impaired children for whom atypical vowel development is characteristic. One study has used acoustic measures to examine the vowel production of language delayed children but I have found no studies which use acoustic measures to
examine the vowel development of children with phonological disorders. I will review some of the research on vowel production of the hearing impaired and the one study using language delayed subjects.

Hearing-Impaired Children

Hiki and Kagami (1975) studied the Japanese vowel production of 35 deaf and hard of hearing children aged 6 to 11 years as compared to 8 normal hearing children aged 7 to 12 years. The children were asked to produce five isolated vowels and F1 and F2 were measured. Overall, there was a significant difference in the frequencies of F1 and F2 for the deaf and hard of hearing group versus the normal hearing comparison. The pattern of differences indicated that the hearing impaired group was using a reduced vowel space, that is, the ranges of F1 and F2 were reduced. Hiki and Kagami identified 6 types of vowel systems in the hearing impaired group:

1. Reduced range of F2
2. Reduced and rotated range of F2
3. Reduced range of F2 with /o/ and /a/ close together
4. Reduced range of F2 with /i/ and /e/ close together
5. Neutralised range of F2
6. Reduced range of F2 with F1 raised

Rubin (1983) was interested in specifying the type of acoustic information found in the

---

4 Details of the methodology employed are not given in the translation from Japanese
vowels of hearing-impaired speakers. Three hypotheses about the abnormal vowel production seen in hearing impaired speakers are presented: 1) the vowel target is absent; 2) the speaker is phonologically deviant; or 3) there is abnormal coarticulation. She determined that these hypotheses could be addressed through an acoustic analysis of the speech of the hearing impaired.

Her subjects were six high school students with congenital, severe-profound, sensory-neural hearing losses and 2 normal hearing high school students. All subjects were of average intelligence and had no other handicaps. Subjects produced the vowels /i, i, e, a, A, u, u/ in words at the end of a carrier phrase. Rubin measured f0, F1, F2 and vowel duration using linear predictive coding and spectrographic analysis.

Results indicated that three types of vowel systems existed. The first was a "point vowel" system in which /i/, /a/, and /u/ were clearly defined. Variability in the point vowel system was greater in the non-point vowels. In addition, the amount of overlap seen in F2 was greater than that in F1. The second was identified as the "front/back" vowel system. In this system, variability was approximately the same in all vowels and a greater amount of overlap was seen in F1 than F2. That is, a front/back (F2) distinction between vowels was well-maintained but a height distinction (F1) was less well-maintained. The third was identified as the "overlapped" vowel system in which the variation was the same in all vowels and there was an equal amount of overlap in F1 and F2.
Monsen (1976) examined the vowel production of deaf adolescents using acoustic measures. He found that the second formant of vowels spoken by his subjects was generally fixed at about 1800 Hz, regardless of the vowel, and that the first formant was restricted in range compared to normal vowel production. Monsen hypothesized that the restriction in the frequency value of F2 was due to reduced visual as well as auditory information. Because his subjects had reduced hearing above 1000 Hz, the frequency region of F2, acoustic information about F2 was distorted or, perhaps, absent. Visual information includes the articulatory information that is available visually. The frequency of F1 is affected largely by the height of the tongue which is, at least in part, affected by the position of the jaw, a visible phenomenon. The frequency of F2 is largely affected by the advancement of the tongue (front/back position) which is much less visible than jaw movement. Therefore, both visual and auditory information relative to F2 is reduced.

In sum, the data on vowel production of hearing-impaired speakers show that there are significant acoustic differences between normal hearing and hearing impaired speakers. Specifically, the ranges of F1 and F2 are reduced as compared to normal vowel production. Several different types of vowel systems have been identified in the literature. This may be due to differences in the ages of subjects, the nature and degree of hearing loss, or some other factor. Since it is sometimes hypothesized that phonological disorders are, in part, due to auditory-perceptual disturbances, it would be interesting to compare the vowel production of phonologically disordered subjects to that of hearing-impaired speakers.
Gilbert (1970) performed acoustic analyses of the vowels produced by five normally developing 4 year olds and five language delayed 4 year olds. The vowels /i, æ, a, u/ were elicited in an [hVd] context. F1 and F2 frequencies were measured and the means and standard deviations for each vowel in each group were calculated. An ANOVA revealed significant differences between vowels but no differences between the groups. Listening tests were then performed using both groups of children and a group of adults. All three groups made significantly more errors in identifying the vowel productions of the language delayed group in the absence of a significant difference in the F1 and F2 values between the two groups of children. Gilbert concludes that vowel perception must be based on something more than purely the acoustic information. More errors were made in identifying the vowels of the language delayed children since they were at a less mature stage in phonological development.

Summary

Acoustic phonetic data on vowel production which is atypical is scarce. With the exception of a single investigation of vowels in language delayed children, the data are limited to the vowel production of hearing impaired speakers. Certainly, there is a gap in the area of phonological disorder. The reports of vowel disorders are increasing and it is necessary to begin gathering acoustic data on disordered vowel production.
4.3 Intervention Studies: Atypical Development

The only studies which address the issue of the effect of intervention on the production of vowels come from the literature on deaf and hearing-impaired speakers. In these studies, investigators are attempting to evaluate the efficacy of intervention which directly targets vowel production. Both acoustic measures and perceptual judgements are used to compare pre- and post- treatment vowel production. Generally, improvements due to intervention occur. Just one study from this literature is reviewed to familiarize the reader with the methodology used.

Osberger (1987) used acoustic measures and perceptual judgements to evaluate the improvement in vowel production of two profoundly hearing-impaired adolescents. The vowels /i/ and /æ/ were targeted in a highly structured and systematic speech training program for 20 minutes a day, four days a week for seven months. The vowels were trained in a variety of structures but only CVC contexts were used for evaluation. The vowels /i/, /æ/, /I/, and /e/ were elicited twice in each of 10 words. For /i/ and /æ/, only five of the ten words were used in the intervention program. Osberger was then able to examine generalization from trained to untrained words and from trained to untrained vowels. Listeners, experienced in listening to the speech of hearing-impaired speakers, rated the acceptability of vowels on a scale of 1 to 5. F1, F2, and duration of each vowel were measured.

For the trained vowels, /i/ and /æ/, the results did not show any significant differences
between trained and untrained words on any of the dependent measures (F1, F2, duration, vowel acceptability). For S1, duration of the trained vowels was not significantly different after treatment, changes in F1 and F2 were significant only for /æ/, although changes did occur for /i/, and the acceptability rating improved for both vowels. For S2, significant changes occurred in F1 and F2 for both vowels, the duration of both vowels increased significantly, resulting in an abnormally long duration, and the acceptibility rating improved for both vowels, more for /i/ than /æ/. For both subjects, F2 of both trained vowels remained significantly different from normal.

For the untrained vowels, no significant improvements in acceptability ratings occurred. The results for S1 show a significant change in the value of F2, the change for /i/ being greater than the change for /e/, and the durations of the two untrained vowels decreased significantly. There were no significant changes after treatment in either F1 or F2 of the two untrained vowels for S2. The duration of both vowels increased for S2 and was longer than normal both before and after training. The acceptibility ratings for S2’s untrained vowels decreased following training.

Token-to-token variability was also addressed. Overall, variability was greater in the hearing impaired subjects than in the normal hearing controls. The variability in the trained vowels for S1 decreased for F1, duration, and vowel acceptability, while F2 variability remained the same. For S1’s untrained vowels, however, variability increased on all measures. The variability in both the trained and untrained vowels for S2 showed
inconsistent changes. In general, however, the trend in the post-treatment data was to reduced variability.

Thus, Osberger did find generalization from trained to untrained words containing vowels targeted during treatment. Changes occurred in both acoustic and perceptual measures. She did not, however, find generalization from trained to untrained vowels. She concluded that, at least for the two hearing-impaired speakers studied, it was useful to target individual vowels directly.

This finding is in contrast with current conceptions of phonological disorder, that is, that segments need not be directly targeted in order for changes to occur. If a child acquires a feature in one segment which is absent in the whole system, it is hypothesized that other segments containing the feature will show evidence of it.
Subject

S was one of six subjects (S5) in a doctoral research study investigating the application of non-linear phonological theory to the assessment and remediation of developmental phonological disorders. He was 6;2 to 6;6 during the period of the study. Canadian English is the language spoken in his home and the first language of both parents and the speech-language pathologist. Previous assessment indicated a mild cognitive delay, a manual intention tremor, an oral motor component, and a moderately severe language disorder. Of the six subjects in the doctoral study, S was the most severely impaired with respect to factors other than phonology. He was chosen as the focus of the present study because of the degree of phonological disorder apparent in his vowel system.

S’s hearing was screened and was found to be within normal limits. An oral mechanism examination revealed mild neurological signs. There is a delay in approximating tongue movements and his tongue deviates slightly to the left on protrusion. He tends to jut his mandible forward when approximating his upper and lower teeth and clench his teeth when making ‘new’ speech sounds. At the time of initial assessment, repetition of syllable sequences was slow but accurate. He was stimulable for all speech sounds with the exception of /dʒ/ and word initial /r/. Stimulability for vowels is not specifically reported. S has a quiet and sometimes tremulous voice which may have increased vowel variability and gliding. He sometimes articulated with very minor drooling.
S had previously attended therapy for language stimulation as well as phonology. This included three months at age 4 years, one month at age 5 years, and six months in the school system prior to the doctoral study. The intervention block immediately prior to the doctoral study resulted in acquisition of velar consonants and an increased use of prepositions, 'is', and articles, but no change in targeted word-initial /l/ and /st/.

Data

Word tokens which targeted one of the six phones originally chosen for acoustic analysis ([i], [ɛ], [æ], [u], [ɔ], and [a]) were selected from the original data. These six phones were selected primarily because they were among those typically analysed in previous acoustic phonetic studies and, thus, a comparison of S to typically developing children was possible. They also cover a range of stages in developmental phonology as defined by Stoel Gammon and Beckett Herrington (1990) and represent a range of accuracy in S's vowel production from most to least accurate. Phonological analysis was performed using all vowels present in the words chosen.

Method

Original data were recorded on a Nagra IV reel-to-reel tape recorder with a AGK D202 microphone on Ampex 631 low noise tapes. The standard procedure for collecting data was single word elicitation using objects and pictures although some words elicited through imitation and some occurring in phrases were included for analysis in both the doctoral study and the present study. Intervention consisted of three six week blocks of therapy with three
45-60 minute sessions per week. A phonological reassessment, including the same list of elicited single words and a conversational speech sample, was performed at the end of each block to evaluate progress and set goals for the next therapy block.

The recordings used for the present study are from (1) the initial assessment session, and (2) a reassessment after two therapy blocks. During the two therapy blocks targets were /l/, the alveopalatals, /r/ in some contexts, and /st/. The reassessment after only two therapy blocks was chosen because vowels were targeted during the third block of therapy. Since the present investigation is focuses on the effects of therapy which does not target vowels, the third therapy block could not be included. A total of 254 tokens was chosen resulting in 404 vowels available for analysis. A subset of these vowels (283) were chosen for acoustic phonetic analysis but a small number (19) were discarded because of difficulty reading either the spectrogram or the LPC section. It was not possible to limit the phonetic environments of the vowels used in the acoustic analysis because of the small number of vowels in single environments. The data, therefore, were chosen to represent each of the vowel phonemes in a range of phonetic environments elicited in a variety of ways.

Phonetic transcription was initially performed by the doctoral candidate using a Revox reel-to-reel tape recorder and Videoconcepts F700 dynamic earphones. Intra- and inter-observer reliability was checked for these initial transcriptions and was considered to be adequate. I independently transcribed only those vowels chosen for analysis and resolved any disagreements by choosing one of the two transcriptions. Each vowel token was then coded
for target phoneme, phonetic realization, number of syllables, syllable shape, and syllable position.

Using two Revox reel-to-reel tape recorders, E dubbed tokens from the original recording to a second tape so that they could be isolated. The tokens were then digitized using a 12 bit analog to digital converter with a 20 kHz sampling frequency. E performed vowel analysis using MacSpeech Lab II, version 1.4, running on a Macintosh IIx. The procedure for analysis was as follows: a wide-band spectrogram of the vowel to be measured was made and the steady state portion of the vowel was identified. The centre of the steady state portion was calculated as a guide for LPC analysis.

E then chose a Linear Predictive Coding (LPC) window display. LPC analysis was performed using 30 coefficients rather than the default value which is based on analysis of an adult male’s voice. E identified a well-defined LPC section, as close to the centre of the steady state as possible. An LPC section was considered well-defined if formants one through three could be identified and if the frequency of these formants appeared to be the same in nearby sections. The frequency values of the formants were then measured and recorded. In cases where two peaks occurred in the region of one formant, E estimated the centre frequency of the formant.

E then chose a fundamental frequency ($f_0$) display window and plotted $f_0$. E measured $f_0$ where the LPC section was taken. In cases where $f_0$ was not measureable (eg where the
frequency resolution was too poor for the program to take an accurate reading), one value was taken from either side of the identified measurement point and the average of these two values was calculated.

Reliability of the acoustic measurements was examined by having a second investigator follow the above procedure for 30 items. Statistical analysis (t-tests) indicated no significant differences between the original measures and the reliability measures on any of the repeated measures. Therefore, frequency values can be considered reliable.

E performed both phonological and acoustic phonetic analyses of the data. A description of the types of analysis is found in the results section of this thesis.
6. Results and Discussion

I shall report first the results of the phonological analysis. For both phonological and acoustic analyses, pre-treatment results will be presented and then compared to post-treatment results.

6.1 Phonological Analysis

Pre-treatment results

Overall, S produced only 46% of his vowels correctly before treatment. All of his vowel errors occurred in monophthong vowels: diphthongs were all produced correctly. Of the monophthong vowels, only /æ/ was absent from S's phonetic inventory. It was always produced as a back rounded vowel, either [u], [o], or [o]. Phonetic context did affect which phone occurred. Accuracy rates for the remaining monophthong vowel phonemes are presented in table 6.1. S's vowels fell into three groups: high accuracy (86-100% correct), /i/, /a/, and /o/; mid accuracy (32-40% correct), /e/, /æ/, /a/, and /u/; and low accuracy (8-20% correct), /u/, /u/, and /a/. A closer analysis of /a/ indicated that many errors were due to an alternation between [a] and [a], reflecting a dialectal variation¹. If this alternation is ignored, /a/ is then 71% correct, falling closer to the high accuracy group, and S's overall accuracy is increased to 52%².

¹ There is also an alternation seen in the phoneme /æ/ between [æ] and [a] but since this alternation is rare in the dialect, occurrences of [a] will still be considered errors.

² All further accuracy rates are calculated ignoring [a]/[a] alternations.
Table 6.1 Accuracy rates for vowel phonemes before treatment.

<table>
<thead>
<tr>
<th>Phoneme</th>
<th># correct</th>
<th>total #</th>
<th>% correct</th>
</tr>
</thead>
<tbody>
<tr>
<td>i</td>
<td>31</td>
<td>34</td>
<td>91</td>
</tr>
<tr>
<td>i</td>
<td>3</td>
<td>15</td>
<td>20</td>
</tr>
<tr>
<td>e</td>
<td>7</td>
<td>22</td>
<td>32</td>
</tr>
<tr>
<td>æ</td>
<td>9</td>
<td>23</td>
<td>39</td>
</tr>
<tr>
<td>ø</td>
<td>3</td>
<td>8</td>
<td>38</td>
</tr>
<tr>
<td>œ</td>
<td>2</td>
<td>2</td>
<td>100</td>
</tr>
<tr>
<td>ø</td>
<td>2</td>
<td>25</td>
<td>8</td>
</tr>
<tr>
<td>u</td>
<td>6</td>
<td>15</td>
<td>40</td>
</tr>
<tr>
<td>o</td>
<td>19</td>
<td>22</td>
<td>86</td>
</tr>
<tr>
<td>a</td>
<td>4</td>
<td>24</td>
<td>17</td>
</tr>
<tr>
<td>a/a</td>
<td>17</td>
<td>24</td>
<td>71</td>
</tr>
</tbody>
</table>

Analysis along the front/back dimension indicated little difference between front (53% correct), central (50% correct), and back vowels (51% correct). With respect to height, high vowels were the least accurate (47% correct), followed by low vowels (55% correct) and then mid vowels (57% correct). Tense vowels were more accurate (56% correct) than lax vowels (47% correct). Unrounded vowels were more accurate (56% correct) than rounded vowels (44% correct). An analysis of the effect of word shape indicated little difference in accuracy between vowels in monosyllabic (52% correct) versus multisyllabic (53% correct) words but a substantially greater accuracy rate for vowels in open syllables (56% correct) as compared with those in closed syllables (42% correct). There may be some relationship between the low accuracy of both lax vowels and those in closed syllables since lax vowels occur only in closed syllables or in open syllables within words.
Results of a substitution analysis for monophthong vowels are presented in table 6.2. Although there is great variability in the data, a primary phone for each phoneme can usually be identified. Following is an analysis of the errors for each phoneme.

Table 6.2 Confusion matrix for monophthong vowels pre-treatment

<table>
<thead>
<tr>
<th></th>
<th>i</th>
<th>e</th>
<th>æ</th>
<th>e</th>
<th>a</th>
<th>o</th>
<th>a</th>
<th>e</th>
<th>ø</th>
<th>a</th>
<th>del</th>
</tr>
</thead>
<tbody>
<tr>
<td>i</td>
<td>31</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>e</td>
<td>7</td>
<td>3</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>æ</td>
<td>1</td>
<td>7</td>
<td>2</td>
<td></td>
<td></td>
<td>11</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ø</td>
<td>9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>13</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>æ</td>
<td></td>
<td></td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ø</td>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td>6</td>
<td>17</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a</td>
<td></td>
<td></td>
<td></td>
<td>6</td>
<td>8</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ø</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td>19</td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>a</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>13</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

S almost always produced the phoneme /i/ correctly. Of the three errors, two appear to be instances of harmony of the feature [-high] (eg. "starry" --> [θtarei]). The third error can only be due to random phonetic variation. The phoneme /i/ is usually transcribed as [i]. It does not surface three times due to deletion of unstressed syllables. As seen for the

---

3 The use of a substitution analysis does not imply that I believe substitution to be a psychologically real process which affected the production of vowels. It is used purely as a descriptive tool since vowel changes did not generally depend on context.
phoneme /i/, two of S’s errors appear to be [-high] harmony (eg. "rabbit" --> [waebet]).

The mid front vowel /e/ is usually correct when followed by an /r/ in the target form, otherwise it surfaces as [a]. The remaining 4 errors appear to be random variation but three out of four occur in open syllables in multisyllabic words. Low front /æ/ varies unpredictably between [æ] and [a], reflecting this alternation in his dialect, but the proportion of [a] productions in S’s speech do not reflect the reported rarity.

The pattern of accuracy seen in the central vowels emphasizes S’s difficulty with unstressed vowels. Whereas /ʌ/ is always correct, /ə/ is infrequently correct. Errors in the production of /ə/ are not predictable but the fact that they are all front vowels may indicate a preference for vowels marked [-back].

The high back vowel /u/ randomly varies between [u], [o] and [u], although it is correct only in open syllables. Its lax counterpart, /u/, also randomly varies, between [u], [o], and [o], but there is no predictability to the correct variant.

The mid back vowel /ɔ/ is usually correct. However, in word initial position, it is transcribed as [o]. Low back /a/ varies between [a] and [a] the majority of the time. Of the seven errors, two are instances of vowel harmony in multisyllabic words (eg. "brontosaurus" → [bɔntoθɔwi]). The other five errors are not predictable.
With the exception of the correct production of /e/, phonetic changes were not sensitive to consonantal context. All vowels except /ʌ/ exhibited variation that could not be explained on a phonological basis. Some of S’s errors can be characterized as vowel harmony but the others all appear not to be affected by context at all. The major patterns are:

\[
\begin{align*}
/i/ & \rightarrow [i] \\
/\i/ & \rightarrow [i] \\
/e/ & \rightarrow [a],[\varepsilon] \\
/e/ & \rightarrow [\varepsilon] \\
/æ/ & \rightarrow [a],[\varepsilon] \\
/\varepsilon/ & \rightarrow [\varepsilon] \\
/\lambda/ & \rightarrow [\lambda] \\
/\varepsilon/ & \rightarrow [\varepsilon] \\
/a/ & \rightarrow [a]
\end{align*}
\]

It appears that S is attempting to enlarge his vowel system from what may have been a four vowel system consisting of a central phoneme, a high front phoneme, a back rounded phoneme, and a low phoneme. The non-high, unrounded phonemes /e/, /æ/, and /a/ may have all been produced as [a] and now S is attempting to differentiate among them. The back rounded vowels may have all been produced as [o] and S is now beginning to differentiate at least /o/. Along with the increase in the number of vowels in his system, an acoustic analysis should indicate a decrease in the allowable variation within each phone. This pattern of results would show that S is narrowing his range of phonetic variation to account for an enlarged phonological system.

**Post-treatment results**

Overall, S produced 50% of his vowels correctly after treatment. With the exception

---

4 Substitutions are listed if they account for greater than 30% of the attempts to produce the phoneme.
of the deletion of one diphthong, all vowel errors occurred in monophthong vowels. The phoneme /ə/ was again the only vowel absent from S's phonetic inventory. With the exception of one occurrence of [ʌ], /ə/ was produced as a back rounded vowel; either [u], [o], or [o]. Phonetic context did not affect which phone occurred. Accuracy rates for the remaining monophthong vowel phonemes are presented in Table 6.3. S's post-treatment vowels fell into three groups: high accuracy (86-100% correct), /i/, /ɪ/, /ɛ/, and /ɑ/; mid accuracy (32% correct), /ʊ/; and low accuracy (0-27% correct), /ɪ/, /ɛ/, /æ/, /ɔ/, and /u/.

Table 6.3 Accuracy rates for vowel phonemes after treatment.

<table>
<thead>
<tr>
<th>Phoneme</th>
<th># correct</th>
<th>total #</th>
<th>% correct</th>
</tr>
</thead>
<tbody>
<tr>
<td>i</td>
<td>30</td>
<td>35</td>
<td>86</td>
</tr>
<tr>
<td>i</td>
<td>4</td>
<td>15</td>
<td>27</td>
</tr>
<tr>
<td>e</td>
<td>5</td>
<td>22</td>
<td>23</td>
</tr>
<tr>
<td>æ</td>
<td>5</td>
<td>23</td>
<td>22</td>
</tr>
<tr>
<td>œ</td>
<td>1</td>
<td>9</td>
<td>11</td>
</tr>
<tr>
<td>æ</td>
<td>3</td>
<td>3</td>
<td>100</td>
</tr>
<tr>
<td>u</td>
<td>9</td>
<td>28</td>
<td>32</td>
</tr>
<tr>
<td>u</td>
<td>0</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>œ</td>
<td>17</td>
<td>19</td>
<td>89</td>
</tr>
<tr>
<td>ø</td>
<td>25</td>
<td>26</td>
<td>96</td>
</tr>
</tbody>
</table>

Analysis along the front/back dimension indicated that central vowels were the least accurate (33% correct) followed by front vowels (46% correct) and then back vowels (68% correct). With respect to height, mid vowels were least accurate (49% correct), followed by
high vowels (54% correct), and then low vowels (61% correct). Tense vowels were more accurate (59% correct) than lax vowels (45% correct). There was little difference in accuracy between rounded and unrounded vowels (53% and 55% correct, respectively). Analysis of the effect of word shape indicated little difference in accuracy between vowels in monosyllabic (54% correct) versus multisyllabic (55% correct) words but a substantially greater accuracy rate for vowels in open syllables (66% correct) as compared with those in closed syllables (43% correct).

Results of a substitution analysis for the monophthong vowels are presented in table 6.4. Again, the data show variability, but a primary phone for each phoneme can usually be identified. Error patterns for each phoneme will be discussed individually.
Table 6.4 Confusion matrix for monophthong vowels post-treatment

<table>
<thead>
<tr>
<th></th>
<th>i</th>
<th>I</th>
<th>e</th>
<th>æ</th>
<th>u</th>
<th>u</th>
<th>o</th>
<th>o</th>
<th>a</th>
<th>a</th>
<th>e</th>
<th>e</th>
</tr>
</thead>
<tbody>
<tr>
<td>i</td>
<td>30</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>10</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>e</td>
<td></td>
<td>5</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>15</td>
<td>1</td>
</tr>
<tr>
<td>æ</td>
<td></td>
<td>5</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>o</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>æ</td>
<td></td>
<td></td>
<td></td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>u</td>
<td></td>
<td>1</td>
<td>9</td>
<td>18</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>u</td>
<td></td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>o</td>
<td></td>
<td></td>
<td>2</td>
<td>17</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>13</td>
<td>12</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The high front phoneme /i/ is usually correct but in word final position of two syllable words where the first vowel is [-high], it sometimes surfaces as [ɪ]. The lax high front /u/ is occasionally correct although usually produced as [i]. One instance of [ei] (in "music box") appears to be due to [-high] harmony.

Mid front /e/ is correct when followed by /t/ in the target but, except for two variants of the low phone, is otherwise produced as [a]. Low front /æ/ is also sometimes correct, although not predictably, but usually occurs as [a]. Central /ʌ/ is always correct but /ɔ/ is correct only once. The errors all occur in closed syllables and indicate that S may have a preference for front vowels.
Although the high back /u/ continues to surface most often as [o], it is sometimes produced correctly. It is correct only in monosyllabic words or as the second vowel in two syllable words. Lax /u/ only occurred twice post-treatment and was produced incorrectly both times, once as [o] and once as [u]. There are insufficient data to draw any conclusions about /u/ errors.

Mid back /ɔ/ is usually correct, except for two transcriptions of [o]. With the exception of one instance of vowel harmony ("doll house" --> [dʌhʌθ]), low back /æ/ varied between [a] and [a].

With the exception of the correct production of /e/ when followed by an /t/ in the target, phonetic changes were not sensitive to consonantal context. The amount of unpredictable variation was greater for front than back vowels. A few of S's errors can be characterized as vowel harmony but the others appear not to be affected by context. Major substitution patterns observed are:

\[
\begin{array}{ll}
/i/ & -> [i] \\
/ɪ/ & -> [i] \\
/e/ & -> [a] \\
/ɛ/ & -> [æ] \\
/æ/ & -> [a] \\
\end{array}
\]

\[
\begin{array}{ll}
/u/ & -> [o],[u] \\
/ʊ/ & -> [o],[u] \\
/ɔ/ & -> [o] \\
/ʌ/ & -> [ʌ] \\
/ɑ/ & -> [a],[a] \\
\end{array}
\]

S appears to be continuing attempts to enlarge his vowel system. A high back rounded phoneme is emerging in contrast with the mid back rounded /ɔ/. S is differentiating the non-high, unrounded phonemes differently than in the pre-treatment data by separating front ([a])
from back ([a]). These changes will be further discussed in the next section.

Comparison of pre- and post-treatment results

The overall accuracy of S's vowel production was only slightly affected by treatment. There were, however, changes in individual phoneme accuracy which should be discussed. Figure 6.1 shows these changes. While the accuracy of /i/, /ʌ/, and /ɔ/ did not change significantly, results for the other phonemes varied. /u/, /u/, and /ə/ increased in accuracy, while /e/, /æ/, /ə/, and /u/ all decreased in accuracy. Accuracy of /i/, /ʌ/, and /ɔ/ probably remained relatively stable over treatment because of their high rates of accuracy relative to the other vowels. I shall discuss the results for /ə/ first, then /u/, then the high back phonemes, and finally, the non-high, unrounded phonemes.

All the target words for /ə/ are multisyllabic in both the pre- and post-treatment data. There are, however two notable differences: 1) five of the eight pre-treatment target words have three or four syllables while all but one of the post-treatment target words have two syllables; and 2) while four of the eight pre-treatment targets are in closed syllables, all but one of the post-treatment targets are. The one post-treatment target word that has three syllables is also the word in which /ə/ is targeted in an open syllable. It is also the only correct production of /ə/ in the post-treatment data. S is better able to produce /ə/ correctly in open syllables in words that are three or more syllables long. The differences in accuracy between the pre- and post-treatment data are due to differences in the target words rather than differences due to treatment.
The slight improvement in accuracy of /i/ indicates that S is gradually becoming able to produce the two distinct high front phonemes. The feature [-tense] is difficult for S to produce and it is slow to be mastered. It would be necessary to follow his vowel development over a longer period of time to determine whether or not the mastery of [i] is truly gradual.
The two high back phonemes show substantial changes in accuracy over the treatment period. The lax phoneme [u] decreased in accuracy from 40% to 0%. This is possibly due to the fact that there were only two tokens in the post-treatment data. The substantial improvement in accurate production of [u] cannot, however, be explained on the basis of differences in the two sets of data. In both sets of data, /u/ is correct in open syllables only, although it is not always correct in open syllables. Consonantal context does not affect accuracy. It appears that /u/ is being mastered gradually and that correct production is occurring first in open syllables.

The nonhigh unrounded vowels have some interesting results. In these three phonemes, /e/, /æ/, and /a/, changes occur which are not necessarily progressions towards the adult phonological system. The contrast between these three phonemes is frequently neutralized since all three are sometimes produced as [a]. Prior to treatment, /e/ and /æ/ are produced correctly more than 30% of the time, with the majority of errors being productions of [a], and /a/ is produced as [a] 54% of the time and [a] 17% of the time, resulting in 71% accuracy. It appears that a three-way contrast is beginning in the nonhigh unrounded series.

After treatment, rather than indicating further development of the three way contrast, the pattern of accuracy and substitution has changed. The back vowel, /a/, is now produced as [a] half the time and [a] 46% of the time. The two front vowels, /e/ and /æ/, are less accurate than they were in the pre-treatment data because they are now produced as [a] 68% and 70% of the time respectively. S appears to have abandoned his attempt to represent a
three-way contrast in the nonhigh unrounded phonemes in favour of a two-way front/back contrast. It would be interesting to follow the development of these three phonemes across time to see whether or not S follows through with this new hypothesis.

A comment should also be made about the variability seen in the pre-versus post-treatment data. For all phonemes, the number of different phones which appeared as substitutes remained the same or decreased across treatment. That is, phonemic variability, or random error, was reduced overall.

A comparison of the results of different featural groupings is summarized in table 6.5. Along the dimension of tongue advancement, differences between the three levels (front, central, and back), which were not present in the pre-treatment data, emerge post-treatment. Along the dimension of tongue height, the mid vowels decrease in accuracy while the high and low vowels increase in accuracy resulting in a different pattern of results post-treatment. Whereas there were no differences in accuracy between rounded and unrounded vowels pre-treatment, rounded vowels are more accurate than unrounded vowels post-treatment. In both the pre- and post-treatment data, vowels in open syllables are more accurate than those in closed syllables. There are no differences, either pre- or post-treatment, in accuracy of tense versus lax vowels, nor are there differences between vowels in monosyllabic versus multisyllabic syllables.
Table 6.5 Comparison of featural groupings before and after treatment.

<table>
<thead>
<tr>
<th>Featural grouping</th>
<th>% correct Pre-treatment</th>
<th>% correct Post-treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>front</td>
<td>53</td>
<td>46</td>
</tr>
<tr>
<td>central</td>
<td>50</td>
<td>33</td>
</tr>
<tr>
<td>back</td>
<td>51</td>
<td>68</td>
</tr>
<tr>
<td>high</td>
<td>47</td>
<td>54</td>
</tr>
<tr>
<td>mid</td>
<td>57</td>
<td>49</td>
</tr>
<tr>
<td>low</td>
<td>55</td>
<td>61</td>
</tr>
<tr>
<td>tense</td>
<td>43</td>
<td>49</td>
</tr>
<tr>
<td>lax</td>
<td>47</td>
<td>45</td>
</tr>
<tr>
<td>rounded</td>
<td>44</td>
<td>53</td>
</tr>
<tr>
<td>unrounded</td>
<td>47</td>
<td>46</td>
</tr>
<tr>
<td>monosyllable</td>
<td>52</td>
<td>54</td>
</tr>
<tr>
<td>multisyllable</td>
<td>53</td>
<td>55</td>
</tr>
<tr>
<td>open syllable</td>
<td>56</td>
<td>66</td>
</tr>
<tr>
<td>closed syllable</td>
<td>42</td>
<td>43</td>
</tr>
</tbody>
</table>

6.2 Acoustic Analysis

Pre-treatment results

The mean frequency values of F1 and F2 for the 7 phones analysed are presented in table 6.6.
Table 6.6 Mean formant frequency values for 7 phones before treatment.

<table>
<thead>
<tr>
<th>Phone</th>
<th>F1</th>
<th>F2</th>
</tr>
</thead>
<tbody>
<tr>
<td>i</td>
<td>390</td>
<td>2803</td>
</tr>
<tr>
<td>e</td>
<td>494</td>
<td>2370</td>
</tr>
<tr>
<td>æ</td>
<td>809</td>
<td>1986</td>
</tr>
<tr>
<td>u</td>
<td>489</td>
<td>2416</td>
</tr>
<tr>
<td>o</td>
<td>507</td>
<td>1961</td>
</tr>
<tr>
<td>a</td>
<td>435</td>
<td>1733</td>
</tr>
<tr>
<td>a</td>
<td>728</td>
<td>1901</td>
</tr>
</tbody>
</table>

There are some notable differences between the frequencies of S’s pre-treatment formants and those reported for typical children. Specifically, F2 frequencies of S’s back vowels are substantially higher than those of his age peers. Interestingly, this is true of all three back vowels and not just [u] which was identified above as a difficult phoneme for S to produce correctly. A higher F2 with no difference in F1 means that for S the difference between F1 and F2 is larger than that seen in the normal population. Since the difference between F1 and F2 is more closely related to vowel backness, a larger F1/F2 difference suggests that S is producing his back vowels further forward than his age peers. Furthermore, for [a], F1 is lower than expected, suggesting that not only is S producing [a] further forward, he is also producing it with a higher tongue position. It is interesting to note that Berhardt (1990) reported that S has a more forward tongue position than normal and that he exhibited

---

5 MK has been compared to his age peers since Gilbert (1973) found that peer groups determined by measures of physiological age were no more appropriate comparisons than those determined by chronological age.
a slight tongue thrust. S had only recently acquired the back consonants /k/ and /g/ and he was still having difficulty with the alveopalatals at the initial assessment indicating that tongue back position affected consonant as well as vowel production.

Post-treatment results

The mean frequency values of F1 and F2 for the seven phones analysed are presented in table 6.7.

Table 6.7 Mean formant frequencies for 7 phones after treatment.

<table>
<thead>
<tr>
<th>Phone</th>
<th>F1</th>
<th>F2</th>
</tr>
</thead>
<tbody>
<tr>
<td>i</td>
<td>408</td>
<td>2900</td>
</tr>
<tr>
<td>e</td>
<td>522</td>
<td>2797</td>
</tr>
<tr>
<td>æ</td>
<td>761</td>
<td>2052</td>
</tr>
<tr>
<td>u</td>
<td>520</td>
<td>1933</td>
</tr>
<tr>
<td>o</td>
<td>538</td>
<td>2065</td>
</tr>
<tr>
<td>a</td>
<td>677</td>
<td>1815</td>
</tr>
<tr>
<td>a</td>
<td>658</td>
<td>1869</td>
</tr>
</tbody>
</table>

Again, the differences between S’s formant frequencies and those reported for typical children are notable. Post-treatment F2 frequencies of back vowels are still higher than expected but the gap has narrowed for [u] and [a] suggesting that S is now able to produce back vowels with a more typical tongue position. F1 of [a] is still lower than normal but it is closer to the expected value than it was pre-treatment suggesting that S is better able to produce this low back vowel with a low, backed tongue. An additional difference emerged
in the post-treatment data which was not present in the pre-treatment data: F2 frequency of [e] was higher than the reportedly normal value indicating that S may have had some difficulty with the front/back position of the tongue for [e].

Comparison of pre- and post-treatment results

A two (pre- versus post-treatment) by one (fundamental frequency) mixed ANOVA indicated that mean fundamental frequency was significantly different after treatment (F(1,262)=10.12, p<.002). Mean fundamental frequency decreased from 244 Hz to 229 Hz. In addition to the change in mean, standard deviation decreased from 41 Hz to 32 Hz. It is not expected that physical growth can account for this change over 3-4 months. It is possible that increased tension during the initial assessment, since it was the first contact S had had with Dr. Berhardt, resulted in a higher fundamental frequency.

A two (pre- and post-treatment) by seven (seven phones) by two (F1 and F2) mixed ANOVA was performed. Results did not indicate a significant difference in mean formant frequency from pre- to post-treatment for the phones. However, there was a significant two way interaction between phone and formant (F(1,191)=43.83, p<.001) indicating that formant structure was significantly different for each phone. The lack of a three way interaction indicates that the relationship between phone and formant did not change from pre- to post-treatment. The changes relative to normal, therefore, must be seen as trends.

Table 6.8 shows the standard deviation seen for each formant of each phone both pre-
and post-treatment. For all phones, standard deviation of F1 frequency decreased indicating that S gained more precise control over vowel height across the two treatment blocks. The standard deviation of F2 frequency increased for [æ] and [a] but decreased for the other 5 phones. The increase in acoustic variability of F2 for the two low phones may somehow be related to the phonological changes in his low vowels since increased variability can signal impending change in a child's system (Menn, 1976).

Table 6.8 F1 and F2 standard deviations for each phone across treatment.

<table>
<thead>
<tr>
<th>Phone</th>
<th>F1</th>
<th>F2</th>
</tr>
</thead>
<tbody>
<tr>
<td>i</td>
<td>142</td>
<td>597</td>
</tr>
<tr>
<td></td>
<td>78</td>
<td>354</td>
</tr>
<tr>
<td>e</td>
<td>264</td>
<td>460</td>
</tr>
<tr>
<td></td>
<td>89</td>
<td>233</td>
</tr>
<tr>
<td>æ</td>
<td>354</td>
<td>209</td>
</tr>
<tr>
<td></td>
<td>262</td>
<td>220</td>
</tr>
<tr>
<td>u</td>
<td>115</td>
<td>677</td>
</tr>
<tr>
<td></td>
<td>88</td>
<td>350</td>
</tr>
<tr>
<td>ɔ</td>
<td>157</td>
<td>635</td>
</tr>
<tr>
<td></td>
<td>104</td>
<td>436</td>
</tr>
<tr>
<td>a</td>
<td>185</td>
<td>212</td>
</tr>
<tr>
<td></td>
<td>179</td>
<td>297</td>
</tr>
<tr>
<td>a</td>
<td>337</td>
<td>296</td>
</tr>
<tr>
<td></td>
<td>258</td>
<td>244</td>
</tr>
</tbody>
</table>
When compared to intra-subject variability data for the formant frequencies of typically developing 6 year olds, S's formant frequencies are much more variable. Eguchi and Hirsch (1969) represented their data as a ratio of standard deviation to the mean formant value and found that for F1 the ratio varied from 0.091 to 0.108 and the F2 ratio from 0.029 to 0.060. When represented in the same ratio, the results for S indicate substantially higher standard deviation to mean ratios for both F1 and F2 than those in Eguchi and Hirsch's subjects. S's F1 ratio varied from 0.170 to 0.534 and F2 from 0.083 to 0.324. The fact that there were only five repetitions of each word in the Eguchi and Hirsch data while there were between one and forty-two repetitions of each phone for S may account for some of the variability for S.

The decrease in acoustic variability which occurred across treatment is a typical developmental trend. Eguchi and Hirsch (1969) found that intra-subject variability decreased with increases in age. Between the ages of 6 and 7, the F1 ratio decreased by between 0.006 and 0.032 and the F2 ratio decreased by between 0.005 and 0.012. The results for S show substantially greater decreases in the standard deviation to mean ratios over the two six week blocks than Eguchi and Hirsch found over a whole year of typical development. S's ratios for F1 decreased by between 0.066 and 0.364 while the ratios for F2 decreased by between 0.025 and 0.113, except, of course, for the phones [æ] and [æ] which increased in variability of F2 as discussed above.

For the phone [i], which was sometimes used as a phonemic substitute, a comparison
of those phones which were phonemically correct and those which were phonemically incorrect was performed. A two (pre- and post-treatment) by two (correct and incorrect) by two (F1 and F2) mixed ANOVA did not show a significant three way interaction. There was, however, a significant two way interaction between correct/incorrect and formant (F(1,43)=11.09, p<.01). That is, formant frequencies were different in phonemically correct instances of [i] than in phonemically incorrect instances. The absence of a three way interaction indicates that there was no change from the pre-treatment to the post-treatment data. The data show that first formant frequency of [i] when it was used as a substitute was higher than phonemically correct instances of [i] and that second formant frequency of [i] substitutes was lower than that of phonemically correct [i]. This indicates that when [i] is used as a substitute, it is produced with a lower, more fronted tongue position than when it is phonemically correct.

For the phone [a], which was used as a substitute for /ɛ/, /æ/, and /ɑ/, a two (pre- and post-treatment) by three (/ɛ/, /æ/, and /ɑ/) by two (F1 and F2) mixed ANOVA was performed to ascertain whether S was making an acoustic distinction where the phonemic distinction was neutralised. No significant interactions occurred indicating that the contrast was neutralised, both phonemically and phonetically, through the production of /a/ both pre- and post-treatment.
7. Conclusion

Previous research in the area of developmental phonology has suggested that vowels are acquired by the age of about 3 years. Research using acoustic methods has found that children’s vowel production continues to change from the age of 3 years essentially until children have stopped growing. It is important to note that both phonological and acoustic phonetic facts about vowel development are important since intelligibility is affected by both. Within the phonological literature, little information is available about developmentally normal vowel errors. The acoustic phonetic literature contains no analysis of phonemic vowel errors in normally developing children. Clinically, disorders of the vowel system are reported as rare, thus phonological and acoustic phonetic descriptions of disordered vowel systems are also rare. With the exception of the literature surrounding the vowel production of deaf speakers, investigations of the effects of intervention on disordered vowel systems have not been conducted.

The purposes of the present study were: 1) to provide descriptions, both phonological and acoustic, of the vowel system of a child who exhibited a phonological disturbance in his vowel system, and 2) to examine the effects that intervention targeting consonants would have on his vowel system. No specific hypotheses were proposed, although it was implied that there would be some effect.
Both phonological and acoustic descriptions of the data are provided. Results of phonological analysis showed that S had a large phonetic inventory of vowels with a high proportion of vowel errors (see Tables 6.1 and 6.3). Only the rhotic phoneme /ɾ/ was absent from his phonetic inventory. Errors in other phonemes exhibited considerable variability but there was usually one phone which could be identified as the primary substitute within each phoneme (see Tables 6.2 and 6.4). Vowel errors were generally not sensitive to consonantal context and vowel harmony accounted for relatively few of the errors. Vowels were substantially more accurate in open than closed syllables.

A high front vowel, a back rounded vowel, a low vowel, and a central vowel were among those most accurately produced by S. Previous research has shown that this is the case for both normally developing and phonologically disordered children. However, although /i/ is the high front vowel and /a/ is the low vowel, consistent with previous findings, the phoneme /ɔ/ as the back rounded phoneme is less common, although /ɔ/ is reported as occurring early by some researchers. The high proportion of errors seen in /u/ appears to be an idiosyncratic characteristic of S’s vowel disorder since /u/ is more commonly an early occurring or more accurate back rounded phoneme. Errors seen in the non-high unrounded vowels are not as uncommon as those seen for /u/, due to two factors. First, there is a non-significant alternation seen in the low vowel series in Vancouver dialect. Second, there is a difficulty with the non-high front phonemes /ɛ/ and /æ/ which has been reported in earlier literature.
With respect to previous reports of phonological vowel disorders, S is both similar and different. He is similar to Hargrove's (1982) subject Vic in that they both have full vowel inventories except for the rhotic vowels. Their patterns of error for the rhotic vowels were the same, that is, production of [ɔ], [o], or [u]. Like Vic, a primary substitute can be identified for each phoneme but there is much variability. With the exception of the rhotic vowel errors mentioned above, S's error patterns are not similar to Vic's.

S falls into Stoel-Gammon and Beckett Herrington's (1990) first category of children with phonological vowel disorders, that is, he has a large vowel inventory but a high proportion of vowel errors. Like both G1 and G2, S has a central, a high front, a back rounded, and a low vowel among his most accurate vowels (post-treatment). Like G1, S exhibits a great deal of lowering/backing, resulting in [a] substitutions for /e/ and /æ/. His error patterns do not resemble those of G2.

S's vowel errors are consistent with the findings of Pollock and Keiser (1990) in three ways. Vowel harmony accounts for only a small proportion of the vowel errors; /i/ and /ɔ/ are among the most accurate vowels and /æ/ and /u/ are among the least accurate; and backing and lowering account for a large percentage of the vowel errors. Whereas Pollock and Keiser found that /u/ was among the most accurate vowels in their group, it is highly inaccurate for S.
It is difficult to compare these results to those of Reynolds (1990) since the dialect he was considering differs in many ways from S’s. Nevertheless, some comparison may be made. Consistent with Reynolds’ findings, context-sensitive errors were rare in the data and a preference for peripheral over central vowels existed, although S’s preference was primarily for front vowels. For S, this preference was most marked in the post-treatment data for /a/. The phoneme /e/ was highly inaccurate although it was not the most inaccurate for S as it was in Reynolds’ survey.

With respect to the representation of vowels discussed in Chapter 2, feature specification, as presented in Table 2.1, does not appear to predict the difficulty S has with vowel production. Actually, S may not have full feature specification. His representation may look more like that presented in Table 7.1. Feature specifications in parentheses imply that presence of the feature is weak.
Table 7.1 Hypothetical feature specification for S

<table>
<thead>
<tr>
<th>Phoneme</th>
<th>Dorsal Node</th>
<th>Labial Node</th>
</tr>
</thead>
<tbody>
<tr>
<td>/i/</td>
<td>[-bk]</td>
<td></td>
</tr>
<tr>
<td>/u/</td>
<td>[-bk],([-ts])</td>
<td></td>
</tr>
<tr>
<td>/ε/</td>
<td>[+lo],[-(bk)]</td>
<td>([ts])</td>
</tr>
<tr>
<td>/æ/</td>
<td>[+lo],[-(bk)]</td>
<td></td>
</tr>
<tr>
<td>/ə/</td>
<td></td>
<td>([ts])</td>
</tr>
<tr>
<td>/ʌ/</td>
<td></td>
<td></td>
</tr>
<tr>
<td>/uo/</td>
<td></td>
<td>[+rd]</td>
</tr>
<tr>
<td>/u/</td>
<td>([ts])</td>
<td>[+rd]</td>
</tr>
<tr>
<td>/ɔ/</td>
<td></td>
<td>[+rd]</td>
</tr>
<tr>
<td>/a/</td>
<td></td>
<td>[+lo]</td>
</tr>
</tbody>
</table>

Acoustically, S's vowels are described as different in some ways from normal. Specifically, the frequency of F2 for his back vowels is higher than expected, suggesting that he may articulate the back vowels with a more fronted position of the tongue, and the frequency of F1 for /a/ is lower than expected, suggesting that he may articulate it with a higher tongue position. In addition to some differences in formant frequency, the acoustic data on S's vowels show much more variability. It is important to note that he exhibited "soft" neurological signs which may have contributed to vowel variability.

There are two findings in the acoustic analyses of phonemically incorrect phones that should be mentioned. First, there was a significant acoustic difference between the phonemically correct and incorrect instances of /i/. I cannot explain this difference and
suggest that it be analysed in further detail. Second, there were no differences between instances of [a] for which either /e/, /æ/, or /æ/ were targeted indicating that the contrasts were truly neutralised.

As assumed, there were effects of intervention both phonologically and acoustically. Some phonological differences between the pre- and post-treatment data were more likely due to differences in the target words rather than effects of intervention while some changes might legitimately be ascribed to treatment. Acoustic changes may be general effects of intervention. Changes included: 1) improvement in the accurate production of /u/, 2) shifts in the non-high, unrounded vowels which are partially neutralised in the production of [a], 3) a decrease in random phonemic error, 4) a decrease in the second formant frequency of back vowels and an increase in first formant frequency of /a/, 5) a decrease in variability of both first and second formant frequency, and 6) a decrease in fundamental frequency.

Whether intervention for the consonants [f], [dʒ], and [l] affected vowel development is not as clear as originally anticipated. If representations of consonants and vowels are non-adjacent at the place node and below, as suggested by Clements (1989a), then there should be no significant changes in vowel place features due to consonant intervention.

The feature [+lateral] was the targeted feature for the production of [l] and it is unlikely that this had any affect on the vowels. For the alveopalatals, however, [-anterior] was one of the features targeted. It is possible that by working towards matching this feature, S was
able to improve his tongue position for back vowel production. I hesitate to conclude that this was a phonological effect on vowel production since relatively small changes in accuracy of the back vowels occurred. It is my suspicion that changes in both phonemic accuracy and acoustic parameters, specifically numbers one through five listed above, are the result of the increased awareness of and control over the speech mechanism which comes from phonological intervention.

Changes in formant frequencies, number four above, were not statistically significant and must be considered trends. Specifically, the second formant of back vowels and the first formant of [ɑ] moved closer to previously reported normal data, suggesting that S was better able to produce these phones with a normal tongue position after intervention.

The most striking change in the data can be observed in the decrease in variability, number 5 above. With the exception of two phones, the ratio of standard deviation to formant mean for each phone decreased substantially more for S over approximately 3-4 months than it did for normally developing children over a full year. This result implies that S gained a significant amount of control over the positioning of his articulators resulting in more consistently similar productions of vowels. It is important to note, however, that the degree of variability seen in S's vowel production is still greater than normal, although this may be due, in part, to the higher number of repetitions in this data than in the normal comparison.
Concerning number six above, the decrease in fundamental frequency, it is possible that the size of S's larynx changed over the time he was involved in intervention resulting in a lower fundamental frequency. It is also possible that, because the initial assessment was his first contact with a new speech-language pathologist, there was more tension in his body, and specifically in the muscles of the larynx, which resulted in a higher fundamental frequency. I can think of no other explanation for this finding.

Were the purposes of this research satisfied? A complete description of the vowel system has been provided, as has both phonological and acoustic data which were compared to both data on normal development of vowels and data on developmentally disordered vowels. It is with this description that the present research makes its most significant contribution.

It was possible to describe differences between the pre- and post-treatment data but it was not possible to ascribe these changes solely to the intervention program. It is difficult to know whether intervention had a direct effect on vowel production or whether the changes which occurred were more general effects of intervention or simply natural events, coincidental with the intervention program. In a sense, this aspect of the study was premature, since essentially nothing is known about the effects that intervention focused on vowels may have on vowel production. In fact, very little is known about the dynamics of disorders of the vowel system in general or the dynamics of disordered vowels within intervention.
In sum, research reported in this thesis has provided a comprehensive description of the vowel system of a child with a phonological disorder who exhibits a high proportion of vowel errors. Results were compared with both normally developing children and phonologically disordered children. A description of changes which occurred in his vowel system over the course of two six week blocks of phonological intervention was provided. It is hoped that the information contained in this study will contribute to the body of knowledge about disorders of the vowel system and provide impetus for further research.
Bibliography


Menn, L. 1976. *Pattern, control and contrast in beginning speech: a case study in the development of word form and word function*. PhD. diss, University of Illinois.


