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AN ACOUSTICAL STUDY OF INDIVIDUAL VOICES
IN CHORAL BLEND

DISSERTATION

Presented to the Graduate Council of the
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DOCTOR OF PHILOSOPHY

By

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The purpose of this study was to investigate the phenomenon of choral blend through acoustical analysis of individual vocal sounds. One aspect of the study involved identifying and comparing the acoustical qualities of sounds produced in the usual solo manner and sounds produced by the same singers attempting to blend with a unison ensemble. Another aspect of the study involved identifying and comparing the acoustical qualities of vocal sounds identified as blending well and poorly with a unison ensemble.

The acoustical qualities studied included the overall intensity, the relative intensity of the fundamental frequency and each partial from 85-8,000 Hz., the frequency and relative intensity of the first, second, and third formants, and the frequency-variation characteristics of the fundamental frequency (vibrato rate and extent). Thirty sopranos were involved singing [a], [o], [u], [ɛ], and [i] on the pitches C⁴ (261 Hz.), A⁴ (440 Hz.), and F⁵ (698 Hz.).

Individual singers first produced tones as though singing a solo. Next they attempted to blend with the sustained vowels of a unison soprano ensemble, prerecorded on tape loops and heard on earphones along with the singer's

own voice. Separate recordings were made simultaneously of each vocal sound combined with the ensemble and isolated from the ensemble. An adjudication procedure identified groups of sounds blending well and poorly with the ensemble. Overall intensity was measured with a sound-pressure-level meter. The spectral characteristics were displayed on sonagrams. The vibrato characteristics were indicated on graphs of fundamental frequency.

In contrast to the sounds produced in solo context, those produced in blend context tended to have: lower levels of overall intensity, stronger fundamental frequencies in combination with fewer and weaker upper partials, stronger first formants, slightly slower vibrato rates, less vibrato extent, and more occurrences of straight tones and nonperiodic oscillations in addition to vibrato. The fundamental frequencies of sounds produced in solo context often varied 27-75 cents above the target frequency. The sounds produced in blend context showed less variation in their fundamental frequencies. The acoustical differences between the sounds identified as blending poorly and well with the ensemble closely resembled, respectively, the acoustical differences between the sounds produced in solo and blend contexts.

Singers attempting to blend adjust their overall intensity not only to affect the perceived loudness of their tones, but also to facilitate other acoustical

changes which are helpful for achieving blend. Vocal blend apparently may be achieved more readily on vowels having few upper partials than on vowels having numerous upper partials. Where vibrato is employed, certain vocal sounds can achieve a good blend even though their fundamental frequencies only approximate the theoretically correct frequency. There apparently is an interaction between the vibrato of a vocal tone and its spectral features, making it advantageous for the singer to adopt mutually beneficial approaches to both factors in order to blend. Vowel modification effective for achieving vocal blend--at least for sopranos--appears to consist primarily of changes in the intensity relationships between the vowel formants. Singers' variations in frequency extend beyond the boundaries of any system of tuning or temperament.

A theory, based on cybernetic principles, was proposed concerning the psychoacoustical factors operating in the individual singer's task of blending with an ensemble. It was recommended that similar studies be conducted with other voice types, and that various acoustic-perceptual phenomena associated with choral singing be investigated.

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TABLE OF CONTENTS

	Page
LIST OF TABLES	vii
LIST OF ILLUSTRATIONS.	xii
 Chapter	
I. INTRODUCTION.	1
Introduction and Purpose of the Study Specific Problems Investigated Points of Analysis Limitations Definition of Terms Basic Assumptions Research Data Available for the Study	
II. REVIEW OF LITERATURE.	9
Concepts of Blend Acoustical Studies of Choral Tone Characteristics of Pitch in Singing Characteristics of Intensity in Singing Characteristics of Timbre in Singing Characteristics of Vibrato in Singing The Pilot Study Additional Observations	
III. METHODOLOGY	32
Introduction and Rationale Overview of Procedures Description of the Ensemble Description of the Individual Subjects Recording Procedures Procedures for Identifying Groups of Sounds Blending Well and Blending Poorly Graphs of Fundamental Frequency Assessing the Spectral Characteristics Assessing the Vowel Formants Producing Spectral Profiles Statistical Analysis of the Data	

TABLE OF CONTENTS--Continued

Chapter	Page
IV. RESULTS OF THE STUDY.	70
Acoustical Qualities of the Ensemble	
Acoustical Qualities of Vocal Sounds Produced in Solo and Blend Contexts	
Additional Observations	
Summary of Acoustical Qualities of Vocal Sounds Produced in Solo and Blend Con- texts	
Acoustical Qualities of Vocal Sounds Identified as Blending Well and Blending Poorly	
Additional Observations	
Summary of Acoustical Qualities of Vocal Sounds Identified as Blending Well and Blending Poorly	
V. DISCUSSION AND INTERPRETATION OF THE FINDINGS	108
Complexity of the Vocal and Aural Processes	
Overall Intensity	
Types of Frequency Variations	
Vibrato Rate	
Pitch Alignment	
Vibrato and Vocal Pitch	
Spectral Characteristics	
The Third Formant	
Effect of the Critical Bands	
Interaction of Vibrato and Spectral Features	
Additional Observations	
VI. SUMMARY AND CONCLUSIONS	180
Introduction and Purpose of the Study	
Specific Problems Investigated	
Points of Analysis	
Limitations	
Methodology	
Results	
Conclusions	
Acoustical Differences of Vocal Sounds Produced in Solo and Blend Contexts	

TABLE OF CONTENTS--Continued

	Page
Acoustical Differences of Vocal Sounds Identified as Blending Well and Blending Poorly	
Choral Blend and the Acoustical Qualities of Vocal Tones	
Cautions Concerning Generalizing the Findings	
A Theoretical Model of the Blend Process	
Recommendations for Further Research	
APPENDICES	219
BIBLIOGRAPHY	337

LIST OF TABLES

Table	Page
I. Interjudge Reliability Expressed in Terms of Percentage of Agreement.	49
II. Criteria for Assessing the Relative Intensities of the Fundamental and Each Partial.	58
III. Formant Frequencies of Vowels for Females	62
IV. Overall Intensity (Decibel Level) of the Ensemble at the Time of Recording	71
V. Mean Overall Intensity (Decibel Level) of Groups of Sounds Produced in Solo and Blend Contexts.	72
VI. Patterns of Change (or No Change) in the Types of Frequency Variations Employed by the Subjects in Solo Singing and in Blending Situations	77
VII. Mean Vibrato Rate for Groups of Sounds Pro- duced in Solo and Blend Contexts.	80
VIII. Mean Vibrato Extent for Groups of Sounds Produced in Solo and Blend Contexts	81
IX. Vowel Formant Frequencies for Vocal Sounds Produced in Both Solo and Blend Contexts.	85
X. Mean Overall Intensity (Decibel Level) of Groups of Sounds Identified as Blending Well and Blending Poorly with a Unison Ensemble.	92
XI. Mean Vibrato Rate for Groups of Sounds Identified as Blending Well and Blending Poorly with a Unison Ensemble	94
XII. Mean Vibrato Extent for Groups of Sounds Identified as Blending Well and Blending Poorly with a Unison Ensemble	95

XIII.	Recorder Specifications	221
XIV.	Acoustical Characteristics of Sounds Sung in Solo Context Vowel [a] Pitch C ⁴ (261 Hz.)	237
XV.	Acoustical Characteristics of Sounds Sung In Solo Context Vowel [a] Pitch A ⁴ (440 Hz.)	238
XVI.	Acoustical Characteristics of Sounds Sung in Solo Context Vowel [a] Pitch F ⁵ (698 Hz.)	239
XVII.	Acoustical Characteristics of Sounds Sung in Solo Context Vowel [O] Pitch C ⁴ (261 Hz.)	240
XVIII.	Acoustical Characteristics of Sounds Sung in Solo Context Vowel [O] Pitch A ⁴ (440 Hz.)	241
XIX.	Acoustical Characteristics of Sounds Sung in Solo Context Vowel [O] Pitch F ⁵ (698 Hz.)	242
XX.	Acoustical Characteristics of Sounds Sung in Solo Context Vowel [u] Pitch C ⁴ (261 Hz.)	243
XXI.	Acoustical Characteristics of Sounds Sung in Solo Context Vowel [u] Pitch A ⁴ (440 Hz.)	244
XXII.	Acoustical Characteristics of Sounds Sung in Solo Context Vowel [u] Pitch F ⁵ (698 Hz.)	245
XXIII.	Acoustical Characteristics of Sounds Sung in Solo Context Vowel [E] Pitch C ⁴ (261 Hz.)	246
XXIV.	Acoustical Characteristics of Sounds Sung in Solo Context Vowel [E] Pitch A ⁴ (440 Hz.)	247
XXV.	Acoustical Characteristics of Sounds Sung in Solo Context Vowel [E] Pitch F ⁵ (698 Hz.)	248

XXVI.	Acoustical Characteristics of Sounds Sung in Solo Context Vowel [i] Pitch C ⁴ (261 Hz.)	249
XXVII.	Acoustical Characteristics of Sounds Sung in Solo Context Vowel [i] Pitch A ⁴ (440 Hz.)	250
XXVIII.	Acoustical Characteristics of Sounds Sung in Solo Context Vowel [i] Pitch F ⁵ (698 Hz.)	251
XXIX.	Acoustical Characteristics of Sounds Sung in Blend Context Vowel [a] Pitch C ⁴ (261 Hz.)	253
XXX.	Acoustical Characteristics of Sounds Sung in Blend Context Vowel [a] Pitch A ⁴ (440 Hz.)	254
XXXI.	Acoustical Characteristics of Sounds Sung in Blend Context Vowel [a] Pitch F ⁵ (698 Hz.)	255
XXXII.	Acoustical Characteristics of Sounds Sung in Blend Context Vowel [o] Pitch C ⁴ (261 Hz.)	256
XXXIII.	Acoustical Characteristics of Sounds Sung in Blend Context Vowel [o] Pitch A ⁴ (440 Hz.)	257
XXXIV.	Acoustical Characteristics of Sounds Sung in Blend Context Vowel [o] Pitch F ⁵ (698 Hz.)	258
XXXV.	Acoustical Characteristics of Sounds Sung in Blend Context Vowel [u] Pitch C ⁴ (261 Hz.)	259
XXXVI.	Acoustical Characteristics of Sounds Sung in Blend Context Vowel [u] Pitch A ⁴ (440 Hz.)	260
XXXVII.	Acoustical Characteristics of Sounds Sung in Blend Context Vowel [u] Pitch F ⁵ (698 Hz.)	261
XXXVIII.	Acoustical Characteristics of Sounds Sung in Blend Context Vowel [ɛ] Pitch C ⁴ (261 Hz.)	262

XXXIX.	Acoustical Characteristics of Sounds Sung in Blend Context Vowel [ɛ] Pitch A ⁴ (440 Hz.)	263
XL.	Acoustical Characteristics of Sounds Sung in Blend Context Vowel [ɛ] Pitch F ⁵ (698 Hz.)	264
XLI.	Acoustical Characteristics of Sounds Sung in Blend Context Vowel [i] Pitch C ⁴ (261 Hz.)	265
XLII.	Acoustical Characteristics of Sounds Sung in Blend Context Vowel [i] Pitch A ⁴ (440 Hz.)	266
XLIII.	Acoustical Characteristics of Sounds Sung in Blend Context Vowel [i] Pitch F ⁵ (698 Hz.)	267
XLIV.	Acoustical Characteristics of a Stratified Random Sample of Vocal Sounds Evaluated a Second Time to Assess the Reliability of the Data Gathering Procedures.	269
XLV.	Group-Mean Differences of Spectra for Vocal Sounds Produced in Solo and Blend Con- texts on the Vowel [a]	272
XLVI.	Group-Mean Differences of Spectra for Vocal Sounds Produced in Solo and Blend Con- texts on the Vowel [o]	273
XLVII.	Group-Mean Differences of Spectra for Vocal Sounds Produced in Solo and Blend Con- texts on the Vowel [u]	274
XLVIII.	Group-Mean Differences of Spectra for Vocal Sounds Produced in Solo and Blend Con- texts on the Vowel [ɛ]	275
XLIX.	Group-Mean Differences of Spectra for Vocal Sounds Produced in Solo and Blend Con- texts on the Vowel [i]	276
L.	Group-Mean Differences of Spectra for Vocal Sounds Identified as Blending Well and Poorly with a Unison Ensemble on the Vowel [a].	278

LI.	Group-Mean Differences of Spectra for Vocal Sounds Identified as Blending Well and Poorly with a Unison Ensemble on the Vowel [O].	279
LII.	Group-Mean Differences of Spectra for Vocal Sounds Identified as Blending Well and Poorly with a Unison Ensemble on the Vowel [U].	280
LIII.	Group-Mean Differences of Spectra for Vocal Sounds Identified as Blending Well and Poorly with a Unison Ensemble on the Vowel [E].	281
LIV.	Group-Mean Differences of Spectra for Vocal Sounds Identified as Blending Well and Poorly with a Unison Ensemble on the Vowel [I].	282

LIST OF ILLUSTRATIONS

Figure	Page
1. Arrangement of Equipment.	38
2. Method for Controlling the Ensemble's Intensity in the Subject's Earphones	41
3. Example of a Graph of a Vocal Sound's Fundamental Frequency	50
4. An Example of a Single-Page Display (Reduced in Size 25 Per Cent) Showing the Acoustical Characteristics of One Vowel Sung at Three Pitch Levels by One Individual Subject	56
5. An Example of Group Spectral Profiles, Based on Group-Mean Intensity Ratings, and Plotted by a Cal-Comp Plotter, Controlled by an IBM 360 Digital Computer.	64
6. Example of a Vibrato Pattern.	73
7. Example of a Straight Tone Pattern.	73
8. Example of a Nonperiodic Variation Pattern.	74
9. Example of a Sound Whose Pattern of Frequency Variation Changed During the Course of the Sound	75
10. Spectral Profiles Showing Typical Differences between the Spectral Characteristics of Vocal Sounds Produced in Solo and Blend Contexts.	83
11. Sonagram of a Soprano Vocal Sound in Which Two Pitches are Being Sung Simultaneously	87
12. Spectral Profiles Showing Typical Differences between the Spectral Characteristics of Vocal Sounds Identified as Blending Well with the Ensemble and Vocal Sounds Identified as Blending Poorly with the Ensemble.	100

13.	Laryngeal Vibratory Cycles at Weak and Loud Intensities.	114
14.	Schematic Representations of Sound Production in Speech.	115
15.	Spectral Differences of "Spread" Quality and "Normal" Quality.	151
16.	Spectral Envelopes (after Winckel), Each Showing Two Formant Peaks	157
17.	The Long-Time-Averaged Spectrum for an Orchestra with and without a Singer	159
18.	A Sonagram Illustrating the Increasing Vibrato Extent of Successively Higher Partial.	167
19.	The Loudness in Sones of Sine Tones in a Room as a Function of Frequency	169
20.	Schematic Representation of Cybernetic Model of Individual Singer's Task in Achieving Vocal Blend with an Ensemble.	209
21.	Frequency Response Curve for TDH-39 Earphone.	222
22.	Group Spectral Profiles Comparing Vocal Sounds Produced in Solo Context and Blend Context for the Vowel [a] and the Pitch C ⁴ (261 Hz.).	284
23.	Group Spectral Profiles Comparing Vocal Sounds Produced in Solo Context and Blend Context for the Vowel [a] and the Pitch A ⁴ (440 Hz.).	285
24.	Group Spectral Profiles Comparing Vocal Sounds Produced in Solo Context and Blend Context for the Vowel [a] and the Pitch F ⁵ (698 Hz.).	286
25.	Group Spectral Profiles Comparing Vocal Sounds Produced in Solo Context and Blend Context for the Vowel [o] and the Pitch C ⁴ (261 Hz.).	287

26.	Group Spectral Profiles Comparing Vocal Sounds Produced in Solo Context and Blend Context for the Vowel [O] and the Pitch A ⁴ (440 Hz.).	288
27.	Group Spectral Profiles Comparing Vocal Sounds Produced in Solo Context and Blend Context for the Vowel [O] and the Pitch F ⁵ (698 Hz.).	289
28.	Group Spectral Profiles Comparing Vocal Sounds Produced in Solo Context and Blend Context for the Vowel [u] and the Pitch C ⁴ (261 Hz.).	290
29.	Group Spectral Profiles Comparing Vocal Sounds Produced in Solo Context and Blend Context for the Vowel [u] and the Pitch A ⁴ (440 Hz.).	291
30.	Group Spectral Profiles Comparing Vocal Sounds Produced in Solo Context and Blend Context for the Vowel [u] and the Pitch F ⁵ (698 Hz.).	292
31.	Group Spectral Profiles Comparing Vocal Sounds Produced in Solo Context and Blend Context for the Vowel [ɛ] and the Pitch C ⁴ (261 Hz.).	293
32.	Group Spectral Profiles Comparing Vocal Sounds Produced in Solo Context and Blend Context for the Vowel [ɛ] and the Pitch A ⁴ (440 Hz.).	294
33.	Group Spectral Profiles Comparing Vocal Sounds Produced in Solo Context and Blend Context for the Vowel [ɛ] and the Pitch F ⁵ (698 Hz.).	295
34.	Group Spectral Profiles Comparing Vocal Sounds Produced in Solo Context and Blend Context for the Vowel [i] and the Pitch C ⁴ (261 Hz.).	296
35.	Group Spectral Profiles Comparing Vocal Sounds Produced in Solo Context and Blend Context for the Vowel [i] and the Pitch A ⁴ (440 Hz.).	297

36.	Group Spectral Profiles Comparing Vocal Sounds Produced in Solo Context and Blend Context for the Vowel [ɪ] and the Pitch F ⁵ (698 Hz.)	298
37.	Group Spectral Profiles Comparing Vocal Sounds Identified as Blending Well and Blending Poorly with a Unison Ensemble for the Vowel [ɑ] and the Pitch C ⁴ (261 Hz.)	300
38.	Group Spectral Profiles Comparing Vocal Sounds Identified as Blending Well and Blending Poorly with a Unison Ensemble for the Vowel [ɑ] and the Pitch A ⁴ (440 Hz.)	301
39.	Group Spectral Profiles Comparing Vocal Sounds Identified as Blending Well and Blending Poorly with a Unison Ensemble for the Vowel [ɑ] and the Pitch F ⁵ (698 Hz.)	302
40.	Group Spectral Profiles Comparing Vocal Sounds Identified as Blending Well and Blending Poorly with a Unison Ensemble for the Vowel [O] and the Pitch C ⁴ (261 Hz.)	303
41.	Group Spectral Profiles Comparing Vocal Sounds Identified as Blending Well and Blending Poorly with a Unison Ensemble for the Vowel [O] and the Pitch A ⁴ (440 Hz.)	304
42.	Group Spectral Profiles Comparing Vocal Sounds Identified as Blending Well and Blending Poorly with a Unison Ensemble for the Vowel [O] and the Pitch F ⁵ (698 Hz.)	305
43.	Group Spectral Profiles Comparing Vocal Sounds Identified as Blending Well and Blending Poorly with a Unison Ensemble for the Vowel [u] and the Pitch C ⁴ (261 Hz.)	306
44.	Group Spectral Profiles Comparing Vocal Sounds Identified as Blending Well and Blending Poorly with a Unison Ensemble for the Vowel [u] and the Pitch A ⁴ (440 Hz.)	307

45.	Group Spectral Profiles Comparing Vocal Sounds Identified as Blending Well and Blending Poorly with a Unison Ensemble for the Vowel [u] and the Pitch F ⁵ (698 Hz.)	308
46.	Group Spectral Profiles Comparing Vocal Sounds Identified as Blending Well and Blending Poorly with a Unison Ensemble for the Vowel [ɛ] and the Pitch C ⁴ (261 Hz.)	309
47.	Group Spectral Profiles Comparing Vocal Sounds Identified as Blending Well and Blending Poorly with a Unison Ensemble for the Vowel [ɛ] and the Pitch A ⁴ (440 Hz.)	310
48.	Group Spectral Profiles Comparing Vocal Sounds Identified as Blending Well and Blending Poorly with a Unison Ensemble for the Vowel [ɛ] and the Pitch F ⁵ (698 Hz.)	311
49.	Group Spectral Profiles Comparing Vocal Sounds Identified as Blending Well and Blending Poorly with a Unison Ensemble for the Vowel [i] and the Pitch C ⁴ (261 Hz.)	312
50.	Group Spectral Profiles Comparing Vocal Sounds Identified as Blending Well and Blending Poorly with a Unison Ensemble for the Vowel [i] and the Pitch A ⁴ (440 Hz.)	313
51.	Group Spectral Profiles Comparing Vocal Sounds Identified as Blending Well and Blending Poorly with a Unison Ensemble for the Vowel [i] and the Pitch F ⁵ (698 Hz.)	314
52.	The Spectral Characteristics of the Vowel [a], Sung at Three Pitch Levels by the Ensemble.	316
53.	The Spectral Characteristics of the Vowel [o], Sung at Three Pitch Levels by the Ensemble.	317

54.	The Spectral Characteristics of the Vowel [U], Sung at Three Pitch Levels by the Ensemble.	318
55.	The Spectral Characteristics of the Vowel [E], Sung at Three Pitch Levels by the Ensemble.	319
56.	The Spectral Characteristics of the Vowel [i], Sung at Three Pitch Levels by the Ensemble.	320
57.	The Acoustical Characteristics of the Vowel [a], Sung at Three Pitch Levels by Sub- ject Number 24.	322
58.	The Acoustical Characteristics of the Vowel [o], Sung at Three Pitch Levels by Sub- ject Number 24.	323
59.	The Acoustical Characteristics of the Vowel [u], Sung at Three Pitch Levels by Sub- ject Number 24.	324
60.	The Acoustical Characteristics of the Vowel [ɛ], Sung at Three Pitch Levels by Sub- ject Number 24.	325
61.	The Acoustical Characteristics of the Vowel [i], Sung at Three Pitch Levels by Sub- ject Number 24.	326
62.	The Acoustical Characteristics of the Vowel [a], Sung at Three Pitch Levels by Sub- ject Number 27.	327
63.	The Acoustical Characteristics of the Vowel [o], Sung at Three Pitch Levels by Sub- ject Number 27.	328
64.	The Acoustical Characteristics of the Vowel [u], Sung at Three Pitch Levels by Sub- ject Number 27.	329
65.	The Acoustical Characteristics of the Vowel [ɛ], Sung at Three Pitch Levels by Sub- ject Number 27.	330
66.	The Acoustical Characteristics of the Vowel [i], Sung at Three Pitch Levels by Sub- ject Number 27.	331

67.	The Acoustical Characteristics of the Vowel [a], Sung at Three Pitch Levels by Sub- ject Number 28.	332
68.	The Acoustical Characteristics of the Vowel [o], Sung at Three Pitch Levels by Sub- ject Number 28.	333
69.	The Acoustical Characteristics of the Vowel [u], Sung at Three Pitch Levels by Sub- ject Number 28.	334
70.	The Acoustical Characteristics of the Vowel [ɛ], Sung at Three Pitch Levels by Sub- ject Number 28.	335
71.	The Acoustical Characteristics of the Vowel [i], Sung at Three Pitch Levels by Sub- ject Number 28.	336

CHAPTER I

INTRODUCTION

Introduction and Purpose of the Study

Achieving a choral blend is often one of the primary objectives in ensemble singing, but directors frequently disagree about the means used to achieve it (4, pp. 9-13; 10, pp. 135-136). Resultingly, there exist various, and sometimes contrasting, approaches to achieving choral blend. Singers may be instructed to align their pitches, to produce uniform vowels, or to make individual adjustments of intensity, timbre, and vibrato in order to achieve vocal blend (4, pp. 9-13).

Approaches wherein individual singers are asked to modify their solo vocal production in the interest of achieving an ensemble blend often are met with distrust, and even hostility, by voice teachers (2, pp. 53-56). Anxious for their students to become excellent solo singers, they sometimes fear that certain ensemble techniques may impede the progress of their students toward individual performance goals.

On the other hand, choral directors typically are more concerned with producing excellent ensembles than in developing individual soloists. Regardless of the concern and controversy, however, little empirical evidence has been

gathered to indicate how vocal sounds produced in solo singing and choral singing may differ acoustically.

"Scientific" evidence from the field of acoustics has been proposed as support for certain techniques used to achieve choral blend. Such techniques include positioning the singers so that all the individuals singing a given part, e.g., soprano, are not grouped together. Rather, the individuals singing various vocal parts are "scrambled" in position. Reportedly, the adverse effect of combination tones on vocal blend is avoided by the above procedure (3, pp. 6-11). Other techniques include the placement of light voices with dark voices so that ". . . the voices cancel out the other's objectionable qualities" (5, p. 18). In some cases it appears that the rationales for such approaches have been based on misconceptions or misapplications of acoustical principles.

The acoustical qualities of vowel sounds which affect their vocal blend have been described by Jones (7, p. 14) and others, but such explanations typically have been merely speculative. As a result, the specific acoustical properties of individual vocal sounds which contribute to their success in blending have largely remained unidentified.

As long as a desired blend is achieved, the average choral director may have little concern for understanding the phenomenon in terms of what occurs acoustically in the individual singers' vocal sounds, e.g., changes in a sound's

partials, vowel formants, vibrato rate, and vibrato extent. However, as certain vocal pedagogs have recognized, there are both aesthetic and scientific aspects involved in singing (1, p. 3; 9, p. 1). To the extent that relevant concepts from scientific areas such as acoustics and aural perception are understood and are incorporated into choral teaching, the reaching of aesthetic goals may be promoted.

For the choral pedagog, the choral musician with a serious scientific curiosity, or anyone aspiring to be knowledgeable in such matters, there is a need for data on which to base teaching approaches and theoretical conceptions of the choral blend phenomenon. A desire for a greater understanding concerning the acoustical nature of choral blend has been expressed by some leaders in the choral field. At the conclusion of a survey of fifty-eight choral directors concerning their approaches to choral blend, Wyatt headed his list of recommendations by stating: "Further study should be made of the acoustical properties of choral tone" (10, p. 141).

The purpose of this study was to investigate the phenomenon of choral blend through acoustical analysis of individual vocal sounds.

Specific Problems Investigated

The following specific problems were investigated:

1. Identification of the acoustical qualities of individual vocal sounds produced in solo singing.

2. Identification of the acoustical qualities of individual vocal sounds produced by singers attempting to blend with a unison ensemble.

3. Comparison of the acoustical qualities of individual vocal sounds produced in solo singing and corresponding vocal sounds produced by the same singers attempting to blend with a unison ensemble.

4. Identification of the acoustical qualities of individual vocal sounds identified as blending well with a unison ensemble.

5. Identification of the acoustical qualities of individual vocal sounds identified as blending poorly with a unison ensemble.

6. Comparison of the acoustical qualities of individual vocal sounds identified as blending well with a unison ensemble and corresponding vocal sounds identified as blending poorly with a unison ensemble.

Points of Analysis

Acoustical data on individual vocal sounds were gathered for each of the following points of analysis:

1. The overall intensity at the time of recording.
2. The relative intensity of the fundamental frequency and each partial from 85-8,000 Hz.
3. The frequency and relative intensity of the first, second, and third formants.

4. The frequency-variation characteristics of the fundamental frequency; specifically, (a) the vibrato rate, and (b) the vibrato extent.

Limitations

1. The blending situation was confined to the unison singing of sustained vowel sounds at a moderate dynamic level. No restrictions were placed on the singers concerning the vocal modifications permitted.

2. The study was limited to soprano voices and included thirty individual subjects, all of whom were college students.

3. The vowels studied included [ɑ], [o], [u], [ɛ], and [i], corresponding respectively to (ah), (o), (oo), (eh), and (ee).*

4. The pitch levels at which the sustained vowels were sung included C⁴ (261 Hz.), A⁴ (440 Hz.), and F⁵ (698 Hz.), representing respectively the low, middle, and high soprano vocal registers (1, pp. 93-94).

5. Only selected segments of the steady-state portions of the individual vocal sounds were examined in spectral analysis.

6. The study was not designed to promote any technique, approach, or point of view concerning choral blend,

*Throughout the study vowel sounds are referred to by the appropriate symbols of the International Phonetic Alphabet.

and basic questions concerning the desirability or appropriateness of choral blend were not investigated.

Definition of Terms

1. For the purposes of this study the term blend refers to a vocal ensemble sound in which, ideally, individual voices are not separately discernible.

2. Throughout this study the term vibrato, unless stated otherwise, refers to oscillations of frequency, not oscillations of intensity or timbre.

3. Steady-state, as the term is commonly used in reference to musical sounds, refers to the portion of sound following the attack, or initiation, of the sound and extending to the moment just prior to cutoff (8, p. 228).

4. Throughout this study the term context refers to mode of performance. Solo context refers to the mode of performance employed in solo singing. Blend context refers to the mode of performance in which a singer attempts to achieve the best possible blend with a vocal ensemble.

Basic Assumptions

1. The approach to choral blend wherein choral singers are encouraged to modify their vocal production as needed in order to achieve choral blend was assumed to be a typical one, though not necessarily the only, nor even the best, approach for achieving choral blend.

2. It was assumed that the vocal sounds produced in the investigative situation were typical of the vocal sounds which would be employed by the subjects in analogous musical situations.

3. The ensemble sounds with which the individual subjects attempted to blend were assumed to represent fairly typical ensemble sounds, although the varieties of choral sound which are possible with different singers and in different musical contexts preclude a universally representative ensemble sound.

Research Data Available for the Study

Although objective information on the acoustical nature of choral blend generally has not been available, studies of the solo voice have provided a basic understanding of certain physical and acoustical aspects of individual vocal production. Research on the physical properties of sound and on aural perception has been conducted in the fields of acoustics, speech, hearing, medicine, psychology, and electronic communication. This body of research literature provided information which served as points of reference for the present investigation. The findings of a number of these studies are reviewed in the following chapter.

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CHAPTER II

REVIEW OF LITERATURE

Concepts of Blend

The concept of blend in vocal ensemble performance is old and well established, existing as a value in widely diverse cultural settings, ranging from Old Testament Israel to contemporary America (4, p. 540; 43, p. 922; 9, p. 90; 8, p. 41; 34, p. 13; 13, pp. 9-13; 60, pp. 135-136). Ideas concerning the qualities most desirable in choral blend have varied at different times. A choral sound emphasizing the prominence of diverse-sounding individual solo voices rather than a homogenous ensemble blend was generally favored in the late nineteenth and early twentieth centuries in American choral performance (24, p. 18; 11, Vol. 11, Foreword). Apparently in reaction to this, the a cappella choir movement, which began in the 1920s, strongly emphasized a choral blend in which individual voices were not separately discernible (24, p. 18).

Six major schools of thought influencing choral singing in America today have been identified (54, p. 8). They represent a diversity of approach to choral tone and place widely varying degrees of emphasis on choral blend (54, pp. 4-55). Increasingly, the trend in attitude concerning

choral blend appears to be one in which choral blend is approached not as an end in itself, but rather, ideally, as a part of the performance practice inferred by the director as appropriate for the style of music as conceived by the composer (54, p. 51; 2, p. 21; 6, p. 9; 14, p. 18; 41, p. 249).

On the basis of the ideas widely expressed in choral books and journals, by a 1967 survey of fifty-eight choral authorities (60, pp. 135-136), and by a series of interviews in 1975 with leading choral directors in this country (13, pp. 9-13), it is evident that there is broad agreement within the choral profession regarding the general factors thought to influence choral blend. These include: rhythmic unity, intonation, vocal timbre, singer intensity, vowel sounds, vibrato, general vocal production, listening, singer selection, singer placement, and aspects of the musical score (e.g., doubling of pitches, tessitura, and chord spacing). Individual directors, however, sometimes contrast greatly in their attitudes toward the concept of choral blend, its appropriateness for various styles of music, and certain techniques used to achieve it, particularly the manipulation of vibrato (40, p. 12; 52, p. 19; 54, pp. 21, 49; 2, p. 12; 13, p. 12; 37, p. 13).

Pedagogical approaches to choral blend often seem to be based on certain assumptions, expressed or implied, concerning how blend occurs (22, p. 8; 55, pp. 224-225; 14,

p. 18). Contrasting approaches, based upon different acoustic assumptions, still seem to achieve what their proponents seek in terms of blend. Limited attempts to support specific techniques (e.g., the "scrambled" positioning of singers) with data purporting to show superiority for acoustical reasons have not always been successful due to misconceptions of acoustical principles (7, pp. 6-11).

Acoustical Studies of Choral Tone

Hunt (20, p. 101), Jones (23, pp. 13-17), and others have approached the matter of choral blend with an apparent understanding of the principles involved. Hunt employed the sound spectrograph to study selected vowels in choral sound. Several choirs were recorded singing vowels on scale passages. The choirs were judged on their choral blend, and sonagrams were made from the taped sounds. Spectrographic analysis revealed that the choral sounds judged as having good blend were characterized by clear, dark, narrow vowel formant bands which were centered fairly well on the frequencies of the partials. In contrast, the choirs judged as having poor blend were characterized by broad, poorly defined vowel formants which spread into frequency regions adjacent to the frequencies of the partials. Hunt drew the following conclusions:

[1] The concept of unity of vowel sound is essential in the achievement of good vocal blend in choral sounds.

[2] The problem of vowel unity in choral sound is a problem of intonation of vowel formant frequencies.

[3] In order to achieve good vocal blend in choral sound, all of the acoustical factors in the choral sound must be aligned with a common natural harmonic series (20, p. 101).

Jones' explanations of the relationship between a sound's fundamental frequency and its vowel formant frequencies were essentially a technical explanation of the acoustical principles demonstrated by Hunt (23, pp. 13-17).

Harper (18) made a spectrographic comparison of certain vowels to ascertain differences between solo and choral singing. The comparison was also made aurally. No consistent differences between solo and choral enunciation were observed aurally, but spectrographic analysis revealed timbre differences. Since the subjects consisted of only seven singers, and there apparently was no attempt to achieve a good ensemble blend, it is interesting that small timbre differences between solo and choral singing were observed.

With the exception of a handful of studies, serious attempts to study the acoustical nature of choral blend have been practically nonexistent. Gonzo, at the conclusion of a review of research conducted in choral music, commented on the dearth of experimental studies relating to choral music.

Unfortunately, very little experimental research is available in choral music. Why this condition exists is not clear, but lack of knowledge of and interest in experimental techniques may account for

this situation. As in theoretical, historical, and descriptive research, experimental research in choral music can play a key role in determining curricular and pedagogical changes. Carefully controlled experiments can certainly aid in pointing the way to new teaching techniques, objectives, content and evaluation and the varying forces of the educational process (15, pp. 30-31).

In evaluating the acoustical characteristics of individual vocal sounds intentionally modified for purposes of choral blend, it may be helpful to consider the findings of previous studies which have dealt with vocal sounds produced in solo singing.

Characteristics of Pitch in Singing

Miles (35, pp. 12-66) found that when a good singer was asked to imitate vocally an interval of a whole step sounded by tuning forks, the interval was approximately correct. Under the same conditions with a semitone, however, the interval was sharpened. A quarter-tone interval was sharpened more, and a tenth-tone interval was sharpened greatly more.

In the case of a tone sung after an organ tone, Sokolowsky observed, in statistical experiments, a discrepancy of ± 0.8 per cent, while in the free singing of intervals, there were considerably larger discrepancies, e.g., in the case of a fifth, 3.3 per cent (58, p. 127).

Winckel indicated that only "first-class artists" were used in the above study (58, p. 127). Seashore (49, pp. 269-270), who by means of the tonoscope was able to measure sung pitches accurately, observed that the professional

singer never reached the desired pitch in 25 per cent of his tones, and in the other 75 per cent the exact pitch was reached only momentarily during the time span of a given note value.

Also using the tonoscope, Schoen (44, pp. 198-199) studied the problem of intonation in singing. He analyzed the recorded voices of five famous opera singers performing the same composition, the Bach-Gounod "Ave Maria." The following were among the conclusions he drew:

A tone is almost invariably attacked below the pitch intended when it is preceded by a lower tone and in the majority of cases it is released above. . . .

A tone is very rarely sustained on the same pitch for an interval of time beyond half a second. . . .

Two tones of the same pitch and of equal duration are never sung twice the same way, but vary in the number and the extent of fluctuations as well as the pitch of the predominant tones.

The vowel quality seems to have but an insignificant effect on the pitch of the tone.

The movement from tone to tone is predominantly in the form of glides, but varies in degree for the different singers. . . .

A tendency for a rise in pitch with a rise in intensity is manifest throughout.

There exists a tendency for all the singers to sing sharp in the sense that the deviations above the predominant tone are more numerous than those below, the maximum deviations below the predominant tone are always larger than those above (44, pp. 198-199).

Grutzmacher and Lottermoser (17, p. 183) found a greater accuracy of frequency in legato singing than in staccato singing. In the latter, deviations as large as a semitone and, occasionally, even a whole step occurred without the discrepancies being particularly noticeable to the ear. Considerable frequency fluctuations were measured

even during the short time of the staccato attacks, which lasted an average of 0.1 seconds. How much these results reflected the singers' perceptions of the pitch as opposed to their vocal control is not clear.

The studies reviewed thus far have concerned solo singers, and the application of their findings to choral singing depends, of course, on whether such singing inaccuracies take place in choral singing.

Wyatt, who surveyed fifty-eight American choral authorities concerning their approaches to choral blend, reported: ". . . the Pythagorean system of tuning is preferred by most authorities because of its high thirds, sixths, and sevenths" (60, p. 77).

However, Lottermoser and Meyer (30, pp. 181-184) found that choral groups sang the major thirds sharp and the minor thirds flat with respect to just intonation. Winckel observed that singers' deviations in pitch were generally so great that they generally extended beyond the difference between absolute and tempered tuning (58, p. 128).

Roederer, citing several recent studies, asserted that inaccuracies in performance have been found to exceed the boundaries of any system of tuning (42, pp. 159-160).

After reviewing a number of studies concerning the actual intonation used by musicians in performance, both singers and otherwise, Backus stated:

It appears that the practical musicians disregard the theorists and play what sounds best, and

the centuries-old arguments as to which tuning is best and which scale is the most "natural" are a waste of time (1, p. 131).

Characteristics of Intensity in Singing

Differences in intensity were found by Wolf, et al. to result as different vowels were sung, the greater intensity occurring on vowels for which the mouth was more open (59, p. 257).

In a study of the relationship between the amount of control singers were able to exercise over their intensity and the amount of training and experience they had, Ekstrom found that: (1) singers were generally more accurate in their ability to control loud singing than soft singing; (2) experienced singers tended to rely on their physical sensations for the control of intensity while inexperienced singers seemed to rely more on auditory sensations; (3) capacity for singing at high intensity paralleled the amount of vocal training and experience; and (4) the accuracy of control of singing intensity generally paralleled the amount of vocal training and experience (10, p. 11).

Characteristics of Timbre in Singing

Large (28, p. 34), after a review of 149 studies related in some manner to the theories of vocal registration, suggested that the main singing registers for artistic Western singing should be termed chest, middle, and head.

His suggestion was proposed "in view of the evidence" and also in order to standardize terminology in vocal research.

In regard to vocal registration, of particular interest for the present study were studies which have produced information concerning spectral differences between sounds produced in different vocal registers. Such studies provided a data base for evaluating the spectral patterns of the vocal sounds produced in the present investigation.

In early studies Katzenstein (25, pp. 271-301) and Sokolowsky (53, pp. 75-91) found that the higher partials were stronger in chest register than in middle register for female singers. This was confirmed by Large in 1968 through sound spectrograms (27, pp. 12-15). In 1974, Large, again using spectrographic analysis, found that for female singers the chest register had more energy than the middle register in all partials except the first, third, and seventh (26, pp. 20-27, 40-41). This study was conducted on the vowel [ɑ] on E⁴ (330 Hz.), where sopranos produced tones alternately in chest and middle register. The study also revealed that singers were able to produce different degrees of register timbre difference.

In studying the spectral differences of the vowels [ɑ], [u], and [i] in male chest register, head register, and falsetto, Scott (46, p. 34) found that between head register and falsetto a change in timbre occurred in addition to a vowel modification. Similarly, in two studies

Winckel (56, p. 93) found that the female middle register exhibited stronger high partials than the head register, but that the fundamental frequencies were of equal strength. Luchsinger and Arnold reported the same finding in 1965 (31, p. 96).

In 1912 Pielke (38, p. 215) found a prominence of the second partial during open singing and weakening of the second partial in covered singing. Covered singing exhibited a stronger fundamental frequency and a richer spectrum of high partials than open singing.

In a comparison of open and covered singing at the same intensity level, Winckel (56, p. 93) found that in covered singing there was a shift of the vowel formants toward lower frequencies and that the fundamental frequencies appeared to be emphasized.

Gemelli, Sacerdote, and Bellussi (12, pp. 3-36), using spectrographic analysis, found that during covered singing the strength of higher partials increased, while the strength of the fundamental frequency decreased.

Schwartz and Rine (45, pp. 1736-1737) determined that the spectra of vowel sounds in speech were somewhat higher for females than for males.

Scott (47, pp. 32-34) studied the effect of changes in vocal intensity upon the spectrum of selected singing tones produced by female singers. Ten subjects sang three vowel sounds, [i], [O], and [U], on the pitch C⁵ (523 Hz.), at

three levels of intensity. Spectrographic analysis revealed that as the tones were produced with less intensity, all the partials except the first decreased in strength, the higher partials disappearing first.

A "ring" occurring at about 2800 Hz. was found by Bartholomew (3, p. 29) to be a common denominator for all well-produced voices. This high formant, Bartholomew speculated, was produced by a forced, shock-excitation of a resonant cavity, which was more or less damped during the period between two successive glottal puffs.

Characteristics of Vibrato in Singing

Seashore defined the characteristics of a "good" vibrato as: "A pulsation of pitch, usually accompanied by synchronous pulsations of loudness and timbre, of such extent and rate as to give a pleasing flexibility, tenderness, and richness to the tone" (50, p. 7). It was found that for the best singers the average extent of the frequency vibrato was approximately a semitone. An intensity vibrato was found to occur at the same rate as the frequency vibrato with an extent of approximately 2-3 db (50, p. 72).

Large (29, p. 42) provided tables displaying similar results reported by Obata (36, pp. 326-329), Sjostrom (51, pp. 123-130), Winckel (57, pp. 232-252), Gemelli (12, pp. 3-8), Bjorklund (5, pp. 575-582), Pommez (39, pp. 249-264), and Mason and Zemlin (33, pp. 12-17).

A recent report by Large (29, p. 46), questioned Seashore's statement that vibrato was utilized in 95 per cent of all artistically sung tones. In a study concerning air flow rates in vibrato and straight tone singing, Large reported that the singing artist Dietrich Fischer-Dieskau used 40 per cent straight tone in a commercially recorded performance of Schumann's Liederkreis, Opus 24 (29, p. 46).

Lundin questioned Seashore's assertion that vibrato was a universal and inherent mode of expression like a smile or a frown (32, p. 273).

Experiments by Seashore and other Iowa researchers indicated that singers exhibiting vibrato characteristics that were not "musically acceptable" could be trained to correct the deficiencies (48, pp. 166-212).

The Pilot Study

A pilot study was conducted by the investigator at North Texas State University during the 1976 spring semester (16). Its purpose was to develop techniques for studying the acoustical properties characterizing individual vocal sounds which were modified for purposes of choral blend from vocal sounds produced in the usual solo manner.

Several sopranos were combined into an ensemble. They rehearsed until they could sing certain vowels on selected pitches throughout their vocal range with a blend of such nature that the careful listener, upon listening to a recording of the ensemble, could not single out an individual

voice. The ensemble was recorded singing a number of these sounds in unison.

Segments of the recorded sound were identified in which no individual voice was separately discernible to the members of the ensemble or to the investigator. Portions of such segments were made into tape loops. When played, a tape loop presented continuously and indefinitely the sound of a well-blended ensemble.

The vowels [α], [o], [u], [ɛ], and [i] were selected for the blending tasks because both open and closed vowels were included. Furthermore, as the vowels used in singing Latin choral texts (21, p. 14), they represented typical vowel sounds employed in choral singing.

Each of the five vowels was studied at three pitch levels, C⁴ (261 Hz.), A⁴ (440 Hz.), and F⁵ (698 Hz.), in order to include sounds from the low, middle, and high soprano vocal registers. This action was taken in response to studies which have revealed that the acoustical properties of the singing voice may change in different vocal registers (26, pp. 20-41; 25, pp. 271-301; 53, pp. 75-91; 56, p. 93; 57, pp. 232-252) and that a vowel's intelligibility may be adversely affected as the fundamental frequency being sung goes above the frequency of the first formant (19, pp. 6-9). The highest pitch upon which tones were sung in the pilot study was above the frequency of the first formant for all but one of the vowels in the

study, [a]. This provided a means for assessing the acoustical features of vowels sung in the pitch range where it has been found difficult for sopranos to produce sounds which are recognizable as different vowels.

Each of the fifteen sounds described above were recorded by individual sopranos singing in two contexts: (1) in the usual solo manner, and (2) attempting to blend with the prerecorded ensemble on the tape loops. In both contexts the individuals monitored their own sounds with earphones as the sounds were sung. The sound of the ensemble was presented to the individuals through earphones also. This procedure made possible the recording of individual vocal sounds which were isolated acoustically from the ensemble sound with which the singer attempted to blend. This, in turn, permitted separate acoustical analysis of the individual and ensemble sounds.

In recording the individual singers, the following procedures were developed. The individual was given a brief description of the nature of the study and an orientation to the recording procedure. To insure that each individual received exactly the same instructions, each was given a set of written instructions for singing the sounds in both solo and blend contexts. The instructions were essentially the same as those used in the present study and included in Appendices B and C.

The singer was first recorded singing the fifteen sounds in solo context. The same sounds were then recorded with the singer attempting to achieve the best possible blend with the ensemble on the tape loops. All recording was done in the same room, which was quiet, but not sound-proof. The microphone distance was the same in both contexts. Within each context the tasks were arranged in random order to control for order effects. The duration of the procedure involved in recording an individual singer was usually 30-45 minutes.

Over 200 sonagrams of the recorded sounds of the ensemble and the isolated sounds of the individual singers were prepared on a Kay Sona-Graph Model 6061A. The acoustical characteristics observed were similar for all the singers and were generally consistent with the findings reported previously in the present review of literature.

The tones sung on low pitches generally had stronger and more numerous partials than the tones sung on high pitches. Vowel differences were clearly evident except at the highest pitch level, at which the spectral differences were minimal. The principal acoustical differences between the individual vocal sounds produced in the solo and blending situations were, in the case of the latter, a marked decrease in the number and relative amplitude of the upper partials and some shifting of energy to lower partials and to the fundamental frequencies.

Graphs of the singers' fundamental frequencies were made. For solo singing, these indicated a vibrato rate ranging from 5-7 cycles per second with a frequency extent averaging approximately a semitone. There was a considerable reduction of the vibrato extent for the sounds produced in the blending situation. Their patterns of frequency variation tended to consist of straight tones, interspersed with some nonperiodic variations. This was not surprising, since the ensemble sounds on the tape loops were essentially vibratoless.

The singers reported that of all the pitch levels, it was most difficult at the lowest pitch level to achieve what they perceived as a good blend. The vowel reported as the most difficult on which to blend was [ɛ], while the vowel reported as the easiest to blend was [u]. These vowels corresponded, respectively, to the vowels which on the sonagrams showed the greatest and the least number of partials. Although the overall intensity of each vocal sound was not measured, it was observed that the overall intensity was reduced for all vowels at all pitch levels when the singers attempted to blend.

Equipment used for the study included a Sony TC-280 stereo tape deck, on which the ensemble was recorded and on which the tape loops were played; a Teac 1230 stereo tape deck, on which the individuals were recorded; Koss ESP-9 electrostatic stereo earphones; an Acoustic Research

Model R stereo amplifier; Realistic electrolet condenser microphones, Model 33-1045A; and Ampex 501 audiovisual high-output, low-noise tape. The tape speed was 7.5 inches per second. Manufacturer specifications for this equipment over the spectral range studied (261-8,000 Hz.) showed a frequency response within ± 0.5 db.

The graphs of fundamental frequency were made using the following equipment: General Radio 1952 universal filter; Electro Mechanical Research Corporation (EMR) Model 287 A-02 subcarrier frequency discriminator, revision B; Esterline Angus Model S-601-S Speed Servo multi-range graphic recorder, using a writing speed of 0.75 inches per second.

Additional Observations

The studies reviewed in this chapter have provided data on various acoustical qualities of vocal sounds produced in solo singing. Most of the studies, however, reported investigating only one or two acoustic parameters of the vocal sounds studied, e.g., only the characteristics of the spectra, overall intensity, or vibrato. In order to use the information from these studies to formulate a conception of the total acoustical qualities typical for individual vocal sounds produced in solo singing, it has been necessary to use data from one study for the spectral characteristics, data from another study for the vibrato characteristics, and data from still other studies for

other acoustical characteristics. The resulting synthesis has remained unclear due to the different purposes of the various studies, the variety of situations in which the vocal sounds were produced, the variety of voice-types studied, and the span of years over which the information was obtained.

A need has remained for a single study to measure simultaneously several acoustical parameters of individual vocal sounds, produced under the same conditions by the same singers. The present investigation provided the means for gathering such information. The methods which were employed in the study are described in the following chapter. Additional studies, relevant to the present investigation, are reviewed in Chapter V in conjunction with a discussion and interpretation of this study's findings.

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CHAPTER III

METHODOLOGY

Introduction and Rationale

A study of the acoustical characteristics exhibited by individual singers as they seek to blend with a choral ensemble presents a number of unique and formidable challenges to the would-be researcher. The basic problem is to isolate the sound of an individual singer from the sound of the ensemble with whom the individual is trying to blend so that the acoustical qualities of the individual singer can be studied alone. In a typical choral situation, such control of the sounds is, for all practical purposes, impossible. However, acoustical isolation of the individual singer and the total ensemble sound can be achieved in a realistic simulation of a choral situation if an individual sings with a high quality stereo recording of an ensemble heard on earphones, while simultaneously monitoring the voice through the earphones. The feasibility of such an arrangement was indicated in a pilot study conducted by the investigator (7). The pilot study was described in connection with a review of literature in Chapter II.

The pilot study provided an opportunity to assess the research value of various approaches. It also provided

means for anticipating and developing procedures for solving various logistical difficulties. Thus, the pilot study served as a developmental model for the procedures used in the present study.

The acoustical analysis of vocal sounds produced in controlled settings rather than in actual performances of musical works is a well accepted practice, having numerous research precedents (3, pp. 25-33; 5, pp. 8-12; 6, pp. 23-26; 17, pp. 255-266; 10, pp. 20-27, 40-41; 8, pp. 18-20). The artificiality of research settings is typically offset by the greater control provided for the research variables. Generalizing the findings of such studies to actual musical performances has not appeared to be seriously questioned.

Overview of Procedures

In the interest of clarity, an initial overview of the basic aspects of the research design will be provided before the procedures are discussed in detail.

A small ensemble of heterogeneous soprano voices was recorded singing sustained vowel sounds in unison with a vocal blend of such nature that the individuals could not single out their own voices when hearing the recordings played back. The ensemble was instructed not to employ a severely reduced dynamic level or a vibratoless tone in order to achieve the blend. Segments of the recordings were made into tape loops. When played for a listener, a

tape loop presented a continuously sounding, highly blended, unison ensemble.

Thirty sopranos were randomly selected from a list of sopranos participating in the principal choral ensembles at North Texas State University during the 1976 fall semester. Individually, each subject sang with the ensemble, which she heard on earphones along with her own voice. The individual subjects attempted to achieve the best possible blend of their own voices with the sustained vowels of the ensemble. Prior to hearing the ensemble tape loops, the subjects were recorded singing the same sustained vowel sounds in their usual solo manner.

As a subject attempted to blend with the ensemble, separate recordings were made simultaneously of: (1) the individual's voice isolated from the ensemble, and (2) the individual's voice combined with the ensemble. The recordings in the latter case were judged on their blend by a panel of six choral directors. On the basis of the judges' evaluations, two groups of individual vocal sounds were identified: (1) those blending well with the ensemble, and (2) those blending poorly with the ensemble.

The acoustical characteristics of all the sounds were assessed by means of the overall intensities measured at the times of recording, graphs made of the fundamental frequencies, and sonagrams, displaying the sounds' spectral qualities. Acoustical characteristics were identified

for the individual vocal sounds produced in the context of solo singing and for the individual vocal sounds produced in attempts to blend with the unison ensemble. Comparisons were made of (1) corresponding sounds produced in solo and blend contexts, and (2) vocal sounds identified as blending well and poorly with the unison ensemble.

Description of the Ensemble

The ensemble consisted of three student sopranos, a sophomore, a junior, and a senior, each of whom was a music education major whose performance concentration was voice. The three individuals were chosen for the ensemble on the basis of their heterogeneous voice-types, their above-average accuracy of pitch and vocal control, and their interest and willingness to participate in the study. In regard to voice-type, the objective was not so much to employ heterogeneous voices in the ensemble as to avoid employing highly homogeneous voice-types in the ensemble.

One of the ensemble singers possessed a large, dark, "operatic style" voice. Another singer possessed a small, light, bright voice. The remaining singer had a voice-type somewhat between the extremes represented by the other two. The above characterizations of voice-type were reflected in the singers' assignments to specific choir sections and also by comments on cards filled out by the North Texas State University choral faculty during ensemble auditions at the beginning of the school year.

The ensemble was instructed at the time of recording to achieve the best possible choral blend, but to avoid a vibratoless tone or a greatly diminished dynamic level. They were told the specific vowel sound to produce, given the appropriate pitch on a Kratt Model MK1-F or MK2-S pitch pipe, and cued to begin after the recording equipment was readied.

After a sound was recorded, it was played back to the ensemble in the soundproof room where the recording was done through KLH Model V loudspeakers. Tape loops were prepared from portions of the ensemble sound in which for three to four seconds neither the members of the ensemble nor the investigator could single out an individual voice. Although in some instances the ensemble sound might be perceived as a single voice, generally it was evident that the sound source was an ensemble, but a well blended one.

The acoustical characteristics of the ensemble sounds were analyzed. The findings are discussed in Chapter IV, where the results of the study are reported.

Description of the Individual Subjects

Thirty students were selected randomly by a means of a table of random numbers (2, pp. 158-161) from the population of sopranos on the attendance rolls of all the principal choral ensembles at North Texas State University during the fall semester of 1976. Each singer was contacted, informed concerning the nature of the study and the

tasks involved, and invited to participate. No individual declined to participate. Three individuals could not participate, due in one case to illness, in another case to a schedule conflict, and in the remaining case to the student's withdrawing from school. Each missing subject was replaced by an alternate, selected randomly as before.

Recording Procedures

All the recording for the study was done in the same soundproof room, located in the North Texas State University Speech and Hearing Clinic. A Teac A-3300S-2T tape deck was used to record the ensemble. Three tape decks were employed simultaneously in recording the individual subjects' attempts to blend with the ensemble. A diagram of the arrangement of equipment is shown in Figure 1.

The ensemble tape loops were played for the subjects on a Teac A-1230 stereophonic tape deck, amplified by an Acoustic Research Model R stereophonic amplifier, and presented through Teledyne TDY-39 earphones, the type earphones commonly used in psychoacoustic experimentation and in audiometry (12, p. 15). The microphones used in recording were a pair of Realistic electrolet condenser microphones, Model 33-1045-A. The mixer functions were built in the recording equipment.

A subject's vocal sounds, isolated from the sound of the ensemble, were recorded on a Teac A-3300S-2T stereophonic tape deck. A subject's vocal sounds, combined with

Fig. 1--Arrangement of equipment

the sound of the ensemble in the manner in which the total sound was presented by the subject's earphones, were recorded separately on a Sony TC-280 stereophonic tape deck.

All the recording was done with virgin Scotch Type 207, high output, low noise, professional mastering tape, using a tape speed of 7.5 inches per second. The technical specifications of the equipment are given in Appendix A.

The overall intensity of a vocal sound at the time of recording was measured by a Bruel and Kjaer Precision Sound Level Meter Type 2203, using the linear scale. Its accuracy was confirmed before each recording session by calibration with a pistonphone, a device supplied with the meter which produces a sound pressure level (SPL) of certified accuracy.

The SPL values of the vocal sounds produced for the study were given in decibels with reference to $0.0002 \text{ dynes/cm}^2$.

Both the recording microphones and the SPL meter microphone were positioned side-by-side at right angles to a singer's mouth. In recording the ensemble, an angle-of-incidence corrector was used with the SPL meter microphone to give an omnidirectional response. A constant distance of twenty-four inches from mouth to microphone was maintained at all times. This was achieved by initially placing a subject at a spot marked on the floor, measuring the mouth-to-microphone distance with a tape measure, and placing small barriers on the floor both in front and behind the subject to restrict movement. Additionally, a subject's position was under observation from the control room a few feet away, where the recording equipment was located.

Each subject was first trained in reading the SPL meter. No further activities were begun until the subject demonstrated an understanding of reading the meter by singing sounds of various intensities and correctly reporting the decibel level to the investigator, who was looking on. As an additional control to insure the subject's accuracy in reporting the SPL meter readings, the VU meters of the recording equipment were calibrated with markings corresponding to the SPL meter readings. The reported SPL meter readings could be verified in each instance by cross-checking them with the calibrated markings on the recording

equipment. The same procedures with regard to microphone distance and training in reading the SPL meter were employed in recording the ensemble as well as the individual subjects.

After orientation in reading the SPL meter, a subject put on the earphones and adjusted them for a proper fit. Earphones were worn by the subjects for all the sounds sung in both solo and blend contexts.

The intensity of the subject's own voice in her earphones was adjusted so that she perceived the loudness of her voice to be the same with the earphones on or off. The intensity of the ensemble in the subject's earphones was controlled so as to be the same as that of the ensemble at the time of recording at a distance of twenty-four inches in front of the ensemble. The method used to achieve this is illustrated in Figure 2.

The method involved determining, for each tape loop, certain fixed settings for the output-level control of the tape deck playing the tape loops. Thus, the sound of the ensemble was presented to the subject's ears at the same level of intensity as it would have been if she had been positioned twenty-four inches in front of the ensemble at the time the ensemble was recorded.

The subject was then given a set of written instructions for singing the sounds in solo context (see Appendix B). The instructions indicated that the subject was to

Fig. 2--Method for controlling the ensemble's intensity in the subject's earphones.

sing the vowel, indicated on a card held up by the researcher, on the pitch given by the pitch pipe. Communication between the subject in the soundproof room and the researcher in the adjacent control room was accomplished via an intercom system, over which the pitch was given.

The subject was asked to sing in the manner she normally would for a solo performance. A moderate level of intensity was suggested, whenever a subject asked how large

a sound she should make. The instructions indicated for her to sing the note, and, when she was producing a sound which she regarded as typical of her solo singing, to hold that sound for about three seconds and then stop. The option of repeating the sound, if necessary, was given. When sounds were repeated, only the last recorded effort was used for the study. The singer was then recorded singing each of the fifteen vowel and pitch combinations in solo context. They were prearranged in random order to control for practice and order effects.

After recording the sounds produced in solo context, the singer was given another set of written instructions for producing the sounds in blend context (see Appendix C). The instructions informed the singer that she would hear an ensemble singing in unison. The vowel which the ensemble was intending to produce was indicated on a card held up by the researcher.

It has been shown that vowel recognition is often dependent on the listener hearing the onset, or attack, of the vowel sound (14, p. 11). The tape loops, however, contained only steady-state portions of the vowel sounds. It was believed that this would have made specific vowel identification difficult in some instances. Thus, the subject was told the ensemble's intended vowel in advance. It was explained to the subject, however, that the intended vowel was merely given as a matter of information, and that she

was to sing whatever sound she felt was necessary in order to blend.

The instructions indicated for the subject to try her best to blend her voice with the ensemble, using any singing technique that she believed would improve her blend. She was told that, ideally, her voice should blend so well with the ensemble that no one listening to them as a group would be able to identify her voice separately. The instructions further indicated that, when the subject was producing the sound which she felt represented the maximum degree of blend with the ensemble that she could achieve, she was to hold that sound for about three seconds and then stop. The option of repeating the sound, if necessary, was given. When sounds were repeated, only the last recorded effort was used in the study.

The subject was then recorded singing each of the fifteen vowel and pitch combinations in blend context. They were prearranged in random order to control for practice and order effects. The total recording time for each subject was approximately one hour.

Procedures for Identifying Groups of Sounds Blending Well and Blending Poorly

At the conclusion of all the recording activities, the subjects' vocal sounds which were produced in efforts to blend with the ensemble were available on two master tapes. One tape contained the individual vocal sounds isolated from

the ensemble sounds. The other tape contained the individual vocal sounds combined with the ensemble sounds. The latter tape was edited to exclude all but the final two or three seconds of each vocal sound just prior to cutoff. This represented the sound of the singer's voice with the ensemble at the point which she felt represented the maximum degree of blend which she could achieve with the ensemble.

In order to identify those individual vocal sounds which blended well and those which blended poorly with the ensemble, the combined sounds of the individuals and the ensemble were submitted to a panel of six selected choral directors. Their task was to rate each sound on its blend. The blend rating finally assigned to a given sound was the mean of all the judges' ratings.

For any given vowel and pitch combination there were thirty sounds, one sound per subject. The group of sounds identified as blending well with the ensemble consisted of the ten sounds with the highest blend ratings. The group of sounds identified as blending poorly with the ensemble consisted of the ten sounds with the lowest blend ratings. Where it was necessary to differentiate between tied values, the mean rating having the least variance among the ratings by the different judges was selected for inclusion within the particular group.

There was no attempt to rate individual singers overall on their blend across all vowels and pitch levels. Rather, the objective was to identify, for each vowel at each pitch level studied, groups of individual sounds blending well with the ensemble and groups of individual sounds blending poorly with the ensemble.

Several steps were taken in developing the procedures for adjudicating the blend of the individual sounds with the ensemble. With each of the thirty subjects attempting to blend on five vowels at three pitch levels, the entire number of sounds which were adjudicated totaled 450. The sounds were placed in random order, numbered in sequence, and spaced approximately seven seconds apart. The adjudication tape was randomized with regard to the order of subjects, vowels, and pitch levels.

The adjudication tape contained a spoken announcement of a sound's order number, followed by the sound of a subject's voice combined with the ensemble, followed by several seconds of silence before the next spoken announcement. This procedure was repeated for all the sounds on the adjudication tape.

Before initiating the blend adjudication task with the selected judges, several procedures were implemented in the interest of achieving a good interjudge reliability. The adjudication tape was listened to by the investigator several times. Several sounds, representing some of the best

and poorest examples of blend, were noted. Examples typifying intermediate degrees of blend were also noted. These sounds were copied onto a training tape, used for orientation of the blend adjudicators. Additionally, the sounds of the ensemble alone were included on the training tape for the judges to hear what the ensemble sounded like by itself.

The training tape, along with a set of written instructions for the adjudicators and a Likert-type rating scale devised for judging the blend of the vocal sounds with the ensemble, were tested on a number of volunteers. The training tape presented aural examples which represented anchor points on the blend rating scale. An ensuing process of trial and error, each time employing a new set of volunteers, resulted in a progressive modification of the materials. After a time, the interjudge reliability increased to a point where the percentage of agreement within ± 1 scale point was approximately 80 per cent. This was considered to be a satisfactory level.

The written materials finally chosen for use in the orientation of the judges included a brief description of the study, an explanation of the adjudication task, and sample pages of the adjudication sheet (see Appendices D and E).

It was found during the tryout phase described above that some individuals experienced difficulty in adjudicating

choral blend on a continuum from the poorest blend to the best blend. Rather, some individuals tended to rate sounds on an either/or basis, i.e., as being either blended or not-blended with the ensemble, even though they readily acknowledged observing varying degrees of blend. Resultingly, an inverse approach was tried, whereby the individual vocal sounds were rated on the extent to which they sounded different from, separate from, or in contrast with the ensemble sound. The extent of contrast between the individual voice and the ensemble was judged to be extremely large, large, moderate, slight, or none, representing a continuum from the poorest blend to the best blend.

The circled responses on the rating scale were transformed to numerical equivalents in terms of blend. A rating of "1" represented the poorest blend, and a rating of "5" represented the best blend. In effect, this amounted to evaluating the blend in reverse. The process, however, seemed to lend itself much better than previous approaches tried for evaluating on a continuum the blend of the individual vocal sounds with the ensemble. This, in turn, better served the ultimate purpose of the blend adjudication activity: to identify for each vowel at each pitch level studied a group of individual vocal sounds blending well with the ensemble and a contrasting group of vocal sounds blending poorly with the ensemble.

Six adjudicators were selected for evaluating the 450 sounds on the blend adjudication tape. All the judges were experienced choral directors with at least a masters degree. Each judge listened to the tape at a different time, convenient for him. To control for possible effects of learning and fatigue, each judge was started at a different place on the adjudication tape. To control for room acoustics, the adjudication tape was played on a Teac A-3300S-2T stereophonic tape deck through the same amplifier and earphones as were used previously by the subjects. The judges were permitted to adjust the loudness of the sound to a desired level. They also were given the option of hearing any sound over again. Rest breaks were taken at each judge's discretion. The adjudication task, from orientation through completion of adjudication, took approximately three hours for each judge.

The interjudge reliability was computed in terms of percentage of agreement within ± 1 scale point. The median value was 79 per cent. The results are summarized in Table I, page 49.

At the conclusion of the recording activities a master tape was available, containing each subject's vocal sounds produced in both solo and blend contexts. On this tape the vocal sounds produced in blend context were isolated from the ensemble sounds. This tape was used in producing graphs of the fundamental frequencies of the individual

TABLE I
INTERJUDGE RELIABILITY EXPRESSED IN TERMS OF
PERCENTAGE OF AGREEMENT*

Judge					
Judge	2	3	4	5	6
1	81%	81%	76%	75%	78%
2		81%	75%	69%	74%
3			82%	79%	80%
4				79%	76%
5					80%

*Percentage of agreement with ± 1 scale point (rounded to the nearest whole number) on a scale from 1-5.

vocal sounds and also in producing sonagrams of the sounds' spectra.

Graphs of Fundamental Frequency

Real-time graphs of the fundamental frequency of each vocal sound were plotted using the following equipment: General Radio 1952 universal filter; Electro Mechanical Research Corporation Model 287 A-02 subcarrier frequency discriminator, revision B; Esterline Angus Model S-601-S Speed Servo multi-range graphic recorder. This equipment

was especially designed for this type of application and was used successfully in previous studies (11, pp. 24-34).

The signal output of the recorded sound was input to a low-pass electronic filter, which completely attenuated all portions of the signal above the fundamental frequency. The signal output of the filter was then input to a graphic recorder, where an ink stylus, moving in accordance with frequency changes in the signal, marked on graph paper a line corresponding to the sound's fundamental frequency. The result was an X-Y graph with the frequency of the fundamental represented in one axis and time represented in the other axis.

The chart writing-speed of the graphs was 0.75 inches per second, and the graph paper contained markings at each 0.25 inch, i.e., each 0.33 of a second. An example of a typical graph is shown in Figure 3.

Fig. 3--Example of a graph of a vocal sound's fundamental frequency.

The exact frequencies of the patterns shown on the frequency-variation graphs were determined by means of calibration markings identifying the intended notes and their adjacent semitones in relation to the equal temperament scale. These calibration markings were plotted from the sounds of the pitch pipes used in the study. The accuracy of the pitch pipes was confirmed by checking their frequency markings against those plotted from an Accutone Tuner, an electronic instrument programmed to produce standard reference tones for the equal temperament scale.

Graphs were produced of the frequency-variation characteristics of each vocal sound in its entirety from attack through cutoff. Photocopies of these graphs were cropped to exclude all but the final 2.0 seconds of the sound immediately prior to cutoff. In the case of a sound sung in solo context, this two-second segment represented a part of the tone which the singer felt was typical of her solo singing. In the case of a sound sung in blend context, the two-second segment represented a part of the tone which the singer felt represented the maximum degree of blend which she could achieve with the ensemble. For a given sound, the frequency-variation graph was mounted immediately below the sonagram of the same sound. An example of this type of display is shown and discussed at a later point. (See Figure 4, page 56.)

For a given sound, assessing the vibrato rate in terms of cycles per second consisted of finding a starting point immediately prior to cutoff and counting the number of cycles shown in the preceding 2.0 seconds, i.e., 1.5 inches. Care was taken to include fractions of a vibrato cycle at the beginning or end of a given two-second segment. The number of cycles (plus fractions thereof) counted for the two seconds was then divided by two to yield a figure representing the rate of the vibrato in cycles per second.

For some patterns of frequency-variation no rates per second could be calculated. Such sounds were evaluated on several criteria and classified as being either straight tones or nonperiodic variations. Examples of these kinds of sounds are shown and discussed in Chapter IV, in which the results of the study are reported.

The vibrato extent for a given sound was determined by measuring at ninety degrees from the horizontal axis the distance encompassed by each cycle's vertical line movement. This was done for each vibrato cycle in the two-second segment analyzed. The figure reported as the vibrato extent for a given sound was the mean of all the vibrato cycles in the two-second segment. To facilitate comparison, the vibrato extent was expressed in cents, i.e., hundredths of a semitone.

The equipment used to plot the graphs was not linear over the range of frequencies graphed. That is, the extent

of a semitone was not represented by equal distances on the graph for different notes throughout the scale. It was necessary for each of the three pitch levels studied, therefore, to calculate the distance representing a semitone.

For the pitch C^4 , 261 Hz., the graph was marked at the adjacent semitones of B^4 and D-flat⁴. The distance between these two points represented two semitones, i.e., two hundred cents. The distance between these points was measured in millimeters, and it was found that each millimeter represented 18.1818 cents. Similar procedures were used to determine constants for the conversion of millimeters to cents at the center-frequency points for the other pitch levels studied, A^4 and F^5 . Using the conversion constants, it was possible to measure the extent of each vibrato cycle in millimeters and then to convert the figure to cents. The use of an illuminated magnifying glass facilitated the above procedures.

To check the reliability of the procedures employed for computing vibrato rate and vibrato extent, a stratified random sample of sounds, including all the vowels at all the pitch levels studied, was measured a second time. The sample included sixty sounds, of which fifteen were classified either as straight tones or nonperiodic variations. For the remaining forty-five sounds exhibiting patterns of vibrato, the correlation coefficient between the first and second measurements of vibrato rate was 0.8898. For the

vibrato extent the correlation was 0.9984. Random samples assessed by two other observers yielded similar figures of correlation with the assessments of the investigator.

Assessing the Spectral Characteristics

The relative intensities of the fundamental frequencies and all the partials from 85-8,000 Hz. were assessed by examining sonagrams made of the individual vocal sounds. Additionally, sonagrams were made of the ensemble sounds on the tape loops (see Appendix M). A Kay Sona-Graph Model 7029-A was used in making the sonagrams. A bandwidth of 45 Hz. was employed. Frequency calibration markings were placed at multiples of 500 Hz. throughout the range of the spectra analyzed.

In addition to the spectra of the sounds intended for analysis, sonagrams may display the spectra of recording machine noise and noise originating in the circuitry of the Sona-Graph. Sonagrams were made of machine noise to aid in distinguishing machine noise in interpreting the sonagrams of the vocal sounds. The sonagrams showed no visible traces of machine noise.

To facilitate comparing the spectral characteristics of the vocal sounds produced in solo and blend contexts, all sounds produced by a given subject on the same vowel at all three pitch levels were displayed side by side on the same sonagram. This procedure also assured that the spectra being compared were produced with exactly the same

machine-control settings and were transferred from the sound recording to the visual lines of the sonagrams in an identical manner. The resulting display provided a visual record of the spectra of each sound, with a graph of its frequency-variation characteristics immediately below the spectral display.

Frequency calibration markings were placed at intervals of 500 Hz. (0.5 kHz.) at the extreme left edge of the sonagrams. At the left edge of each frequency-variation graph were placed calibration markings indicating the frequencies of the pitch levels studied and their adjacent semitones in relationship to the equal temperament scale. In a few cases for vocal sounds produced at the lowest pitch level, C⁴, 261 Hz., it was necessary to make frequency-variation graphs from the first partial above the fundamental frequency. This was due to certain characteristics of the equipment which prevented adequate attenuation of the partial immediately above the fundamental frequency of some sounds. In those cases, the frequency calibration markings were changed to the correct positions to accommodate the nonlinearity of the graphing equipment, as discussed earlier. An example of the displays used to show the frequency-variation and spectral characteristics of the vocal sounds studied is provided in Figure 4, page 56, reduced in size 25 per cent. The displays for three representative subjects are included in Appendix N.

Fig. 4--An example of a single-page display (reduced in size 25 per cent) showing the acoustical characteristics of one vowel sung at three pitch levels by one individual subject. Shown are side-by-side comparisons of the spectra of sounds produced in solo and blend contexts. The corresponding frequency-variation patterns are positioned below each sound's spectral pattern.

As in the case of the frequency-variation graphs, a master tape containing each subject's vocal sounds alone in both solo and blend contexts was used in making the sonagrams. A sonagram displays 2.4 seconds of sound on a piece of paper twelve inches long. One inch, or 0.2 seconds, was used for inserting the frequency calibration markings at 500 Hz. intervals, leaving the remaining 2.2 seconds, or eleven inches, of the sonagram for displaying all six of any one subject's sounds on a given vowel (0.36 seconds per individual sound).

The pilot study indicated that sonagrams in which 0.36 seconds was used for each of the six sounds revealed no critical differences for the purposes of this study from sonagrams in which the entire 2.4 seconds available on a sonagram was used to display a single sound. Since the portions of sound analyzed were all steady-state segments and, thereby, relatively unchanging over time, the short time samples were sufficient. While spectral changes do occur over the duration of a single vibrato cycle, the time sample employed was generally adequate to include two or three complete vibrato cycles.

The segment of sound used for spectral analysis was taken from the final portion of the two seconds of a given sound immediately prior to cutoff. The actual cutoff point, i.e., decay from steady-state, was avoided.

In addition to general visual observations, the relative amplitudes of the fundamental frequencies and the partials were assessed according to their relative darkness on the sonagrams and the amount of sonagram area they covered. An intensity rating ranging from 0-5 was assigned to each fundamental frequency and partial. In an effort to make this procedure as objective as possible, the specific criteria shown in Table II were found useful.

TABLE II
CRITERIA FOR ASSESSING THE RELATIVE INTENSITIES
OF THE FUNDAMENTAL AND EACH PARTIAL

Rating	Meaning	Criteria
0	Nonexistent	No partial visible.
1	Trace	1 mm.* wide or less; barely visible; line not solid across the display.
2	Weak	1 mm. wide or less; faint line extending essentially solid across the display.
3	Moderate	1 mm. wide or less; black; extending solid across the display; not so wide as below
4	Strong	Greater than 1 mm. wide but less than 2 mm. wide; black; solid line.
5	Very Strong	2 mm. wide or greater; black; solid line.

*Millimeter.

The ratings of relative intensity were not intended to represent precise measures of intensity, such as those provided by amplitude-section type sonagrams and by spectrum analyzers. However, assessing the relative intensities of the spectra in the way described above permitted the spectral data evidenced by the sonagrams to be quantified. Expressed as numbers, the relative intensities of the various partials could be compared statistically for the groups of sounds produced in solo and blend contexts and also for the groups of sounds identified as blending well and blending poorly with the ensemble.

It would have been possible to make amplitude-section type sonagrams, which display frequency by intensity. In such displays the exact intensity of each partial is indicated by the length of the lines. However, an amplitude-section type sonagram samples only eight milliseconds of sound, which is much less time than even one vibrato cycle, during which the intensity of individual partials can vary considerably. Only by special modifications of the sonagraph equipment can amplitude sections of longer duration be made.

Frequency-by-intensity displays can also be produced by spectrum analyzers. However, such equipment was not available for the study. Additionally, spectrum analyzers typically do not show spectral changes over time, a useful function for analyzing the effects of vibrato on the vocal

spectra. Therefore, regular sonagrams, displaying frequency by time in the vertical and horizontal axes and intensity by the darkness of the lines, were prepared.

The lack of precision in the ratings of the partials on their observed intensity differences may be offset by the fact that the intensity differences were expressed as different numerical values only when they were readily apparent visually. That is, intensity differences had to be great enough to see. Winckel has noted that extremely precise measures of the intensity of sounds' spectra may result in quantitative differences where, for all practical purposes, there may be no audible differences (16, pp. 115, 118).

To check the reliability of the process for rating the relative intensities of the spectra, a stratified random sample of sounds, encompassing all the vowels at all the pitch levels studied, was assessed a second time. These same samples were used previously in checking the reliability of the processes used in calculating the vibrato rate and the vibrato extent of the sounds. The reliability was computed in terms of percentage of agreement within ± 1 scale point. The figure was 99.49 per cent. Random samples assessed by two other observers yielded similar figures of correlation with the assessments of the investigator.

Assessing the Vowel Formants

Ladefoged has noted a number of difficulties in analyzing particular formant frequencies on sonagrams of speech sounds when certain conditions are present.

The center of formant one is difficult to locate [due to the strength of the fundamental frequency] when it is low in frequency.

When formant one is close to formant two, it is difficult to locate the center frequencies of either of these formants.

Both the above difficulties are considerably increased when the fundamental frequency is high (9, p. 81).

Formant two may also be difficult to locate because it is so much lower in intensity than formant one.

When formant two is low in intensity, formant three is also often difficult to locate for the same reason (9, p. 83).

All the above situations were encountered in the present study, as examination of a few sonagrams will reveal. Ladefoged's procedure in dealing with the difficulties enumerated above was to determine on the basis of previous studies where the formant frequencies were likely to be located and then to find within those regions partials having a relatively high intensity (9, p. 86). A similar approach was employed in the present study.

The frequencies and relative intensities of the first three formants were determined by identifying certain partials whose darkness on the sonagrams indicated those partials to be center-points of energy concentrations. The

frequencies of those partials were evident from their positions relative to the calibration markings appearing at 500 Hz. multiples at the left edge of the sonagrams.

Because it is the nature of formants in soprano vocal sounds to vary somewhat in frequency, depending on the fundamental frequency being sung (4, p. 383), the vowel formant frequencies as given by Appelman (1, p. 226) were found helpful as beginning reference points. These formant frequencies are shown in Table III.

TABLE III
FORMANT FREQUENCIES OF VOWELS FOR FEMALES

Vowel	Formant One	Formant Two	Formant Three
[α]	700 Hz.	1300 Hz.	3250 Hz.
[o]	500 Hz.	1000 Hz.	3000 Hz.
[u]	400 Hz.	800 Hz.	3250 Hz.
[ɛ]	550 Hz.	1750 Hz.	3250 Hz.
[i]	400 Hz.	2250 Hz.	3300 Hz.

(1, p. 226).

On the basis of the reference points derived from Appelman, identifying and assessing the vowel formants on the sonagrams was approached by first marking sheets of clear plastic with calibration markings positioned at the

edges and corresponding to those calibration markings appearing at 500 Hz. multiples on the sonagrams. Next, lines corresponding to the first three formant frequencies (as shown in Table III) were drawn horizontally across the plastic sheet. The plastic overlay was then placed over a sonagram and aligned with the 500 Hz. calibration markings on the sonagram edges. Regions of energy concentration on a sonagram were then compared visually with the formant frequencies as suggested by Appelman.

Producing Spectral Profiles

The ratings of the partials on their relative intensities provided a set of individual values for each partial that could be averaged for a given group of sounds, e.g., the sounds produced in solo or blend contexts. Group-mean values for all the partials of a given vowel and pitch were useful for making quantitative comparisons of the overall spectra of the different groups of sounds. To facilitate such comparisons, a computer program was devised by the researcher to display the group-mean differences visually.

Spectral profiles were plotted by computer as lines on two-dimensional graphs of frequency and intensity. Each X-Y point corresponded to the frequency of a given partial on the X-axis (horizontal) and the same partial's mean intensity rating on the Y-axis (vertical). Lines connecting the points outlined the profile for sounds in a given group. The spectral profiles belonging to different groups

were differentiated visually by employing a solid line for one group and a line marked by small boxes at each plot-point for the contrasting group. An example of this type of display is shown in Figure 5.

Fig. 5--An example of group spectral profiles, based on group-mean intensity ratings, and plotted by a Cal-Comp Plotter, controlled by an IBM 360 digital computer. Each X-Y point corresponds to the frequency of a given partial on the X-axis (horizontal) and the same partial's group-mean intensity rating on the Y-axis (vertical). In the display above the pitch is C^4 (261 Hz.), and the vowel is [ɛ]. The groups of sounds compared are those identified as blending well and blending poorly with the ensemble. The spectral profile of the well blending group of sounds is differentiated by small boxes placed at each plot-point (each partial).

These displays were particularly useful as visual aids for discovering and interpreting spectral differences observed between compared groups of sounds. Vowel formants were identifiable as peaks in the spectral profile, where certain partials were characteristically assigned greater ratings of relative intensity due to their greater darkness on the sonagrams.

Statistical Analysis of the Data

Quantitative data on each point of analysis for the acoustical characteristics studied were produced for each comparison group of interest. Prior to the study, appropriate statistical procedures for using the data to address the research problems were worked out in conjunction with a consultant on research statistics from the Department of Psychology at North Texas State University. These procedures were also developed with the advisement of area university consultants in audiology, speech science, computer science, and music education.

Statistical procedures were employed for two general purposes: (1) computing reliability values for evaluating the procedures whereby the data were gathered and quantified, and (2) comparing group-mean values on the variables of overall intensity, vibrato rate, vibrato extent, and the relative intensity of the spectra. The group means comprised either: (1) the acoustical characteristics of groups of sounds produced in solo context, (2) the

acoustical characteristics of groups of sounds produced in blend context, (3) the acoustical characteristics of groups of sounds identified as blending well with the ensemble, or (4) the acoustical characteristics of groups of sounds identified as blending poorly with the ensemble.

For the individual sounds, the values for vibrato rate, vibrato extent, and the relative intensities of the spectra were determined before the sounds were adjudicated on their blend, i.e., before groups of sounds blending well or poorly with the ensemble were identified. Thus, the values for each sound were determined "in the blind," thereby removing the possibility of bias in calculating the group-mean values.

Statistical procedures such as calculating means or comparing group-means by t-tests require values of interval data. One unit of interval data is assumed to be equal in size to any other unit. Decibel values, used in reporting values of overall intensity, however, represent logarithmic values rather than interval values.

In the case of statistical procedures involving overall intensity, it was first necessary to convert the reported SPL values in decibels (referred to $0.0002 \text{ dynes/cm}^2$) to dynes/cm^2 . This conversion process was a computer operation, automatically performed prior to implementing any statistical procedures involving overall intensity.

The statistical procedures for the study involved extensive use of the North Texas State University Computing Center. Prepared computer programs from the North Texas State University Statistical Library and Statistical Programs for the Social Sciences (SPSS) were used in addition to special-purpose computer programs devised by the investigator.

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CHAPTER IV

RESULTS OF THE STUDY

Results from the two major areas of the study are reported in separate sections of this chapter. In the first section, findings relating to the first three investigative problems are reported: the acoustical qualities of vocal sounds produced in solo and blend contexts. In the last section, findings relating to the last three investigative problems are reported: the acoustical qualities of vocal sounds identified as blending well and blending poorly with a unison ensemble.

Acoustical Qualities of the Ensemble

The ensemble's sounds were acoustically analyzed by essentially the same methods as were used for analyzing the sounds of the individual subjects. (See the discussion on pages 57-63.) Sonagrams of the ensemble's sounds are included in Appendix M.

The ensemble's formant frequencies corresponded generally to those formant frequencies shown for the individual singers in Table IX, page 85. Graphs of the ensemble singers' fundamental frequencies were not included because the graphing equipment was designed to chart only single-frequency signals, not multiple-frequency signals, such as

presented by the combined fundamental frequencies of the different singers in the ensemble.

The overall intensity levels of the ensemble at the time of recording for each vowel and pitch level are shown in Table IV.

TABLE IV
OVERALL INTENSITY (DECIBEL LEVEL)* OF THE ENSEMBLE
AT THE TIME OF RECORDING

	Vowel				
Pitch**	[a]	[o]	[u]	[ɛ]	[i]
F ⁵	92	94	94	92	90
A ⁴	84	84	88	82	84
C ⁴	74	74	72	74	72

*Decibels with reference to .0002 dynes/cm².

**Pitch: F⁵ = 698 Hz., A⁴ = 440 Hz., C⁴ = 261 Hz.

Acoustical Qualities of Vocal Sounds Produced in Solo and Blend Contexts

Overall Intensity

For all vowels and pitch levels, the vocal sounds produced in solo context had a greater level of overall intensity than the vocal sounds produced in blend context. The difference was approximately 5-6 db at the lowest pitch

level, 7-8 db at the middle pitch level, and 7-9 db at the highest pitch level (see Table V).

TABLE V
MEAN OVERALL INTENSITY (DECIBEL LEVEL)* OF GROUPS OF
SOUNDS PRODUCED IN SOLO AND BLEND CONTEXTS

Vowel	Pitch**	Context		t-Value	Degrees of Freedom	Probabil-ity***
		Solo (Decibels)	Blend (Decibels)			
[a]	C4	78.41	73.04	7.56	29	<.001
[a]	A4	84.99	78.11	6.06	29	<.001
[a]	F5	100.86	92.39	5.90	29	<.001
[o]	C4	78.64	72.70	6.86	29	<.001
[o]	A4	84.54	78.55	6.41	29	<.001
[o]	F5	101.09	93.01	5.89	29	<.001
[u]	C4	74.79	69.72	6.64	29	<.001
[u]	A4	87.80	80.84	5.12	29	<.001
[u]	F5	99.92	92.28	5.16	29	<.001
[m]	C4	78.24	72.06	4.57	29	<.001
[m]	A4	83.98	76.17	6.79	29	<.001
[m]	F5	99.88	92.49	5.58	29	<.001
[n]	C4	74.80	69.36	7.41	29	<.001
[n]	A4	88.77	79.60	6.27	29	<.001
[n]	F5	99.23	91.07	5.30	29	<.001

*Decibels with reference to .0002 dynes/cm².

**Pitch: C⁴ = 2.61 Hz., A⁴ = 440 Hz., F⁵ = 698 Hz.

***The probability of the difference between the means occurring by chance if no difference existed in the population means; calculated by a t-test of dependent means; group N = 30.

Frequency-Variation Types Observed

Some sounds exhibited patterns of frequency variation for which values of vibrato rate and vibrato extent could

not be calculated. Three general frequency-variation types were observed: vibrato, straight tones, and nonperiodic variations. Every sound was categorized as one of these three types. Examples of each type are shown respectively in Figures 6-8, pages 73-74.

Time (each vertical line represents 0.33 seconds)

Fig. 6--Example of a vibrato pattern

Vibrato patterns (Figure 6) were characterized by periodic frequency oscillations. For such sounds it was possible to calculate the vibrato rate and the vibrato extent. These figures are reported in Table VII, page 80, and Table VIII, page 81, and are discussed at a later point.

Time (each vertical line represents 0.33 seconds)

Fig. 7--Example of a straight tone pattern

Sounds identified as straight tones (Figure 7) were essentially vibratoless. They tended to rise and fall in frequency rather gradually over a span of several seconds, producing essentially straight-line patterns. Conventional analysis of these sounds in terms of rate and extent, as for vibrato, was not possible. Rather, analysis consisted of observing the frequency of the straight tones in relation to the frequency calibration markings of the intended frequencies and their adjacent semitones.

Fig. 8--Example of a nonperiodic variation pattern

Nonperiodic variations (Figure 8) differed from straight tones in that, generally, there were continuous variations in frequency, resulting in the general absence of straight line patterns. However, the frequency variations did not occur in regular cycles over time. Hence, it was not possible to calculate rates of oscillation per second, comparable to those calculated for vibrato patterns. Neither was it possible in most cases to calculate average values of extent for the cycles of oscillation, since the

cycles of oscillation did not exist in comparable form from sound to sound, nor even throughout the duration of a single sound. As with straight tones, analysis consisted of observing the frequency of the nonperiodic variations in relation to the calibration markings of the intended frequencies and their adjacent semitones.

Some sounds began as one of the frequency-variation types noted previously and changed to another type over the sound's duration. It was not unusual to observe all three frequency-variation types occurring at different points in the same sound (see Figure 9).

Fig. 9--Example of a sound whose pattern of frequency variation changed during the course of the sound.

Of the sounds produced in solo context, approximately 79 per cent had a pattern of vibrato from beginning to end; approximately 3 per cent had a straight tone pattern from beginning to end; and approximately 3 per cent had a non-periodic variation pattern from beginning to end. The remaining 15 per cent of the sounds produced in solo context

had two or more changes in the frequency-variation type over the sound's duration.

In blend context approximately 48 per cent of the sounds had a pattern of vibrato from beginning to end; approximately 16 per cent had a straight tone pattern from beginning to end; and approximately 11 per cent had a nonperiodic variation pattern from beginning to end. The remaining 25 per cent of the sounds produced in blend context had two or more changes in the frequency-variation type over the sound's duration.

A frequency-variation graph was, in essence, a history of a subject's sound from the attack through the cutoff. The graphs were useful in analyzing the variety of approaches used by the different subjects in their efforts to achieve a blend with the ensemble.

In accordance with the instructions given a subject prior to her producing tones in both solo and blend contexts, the segment of sound which the subject regarded as appropriate for the task in each context consisted of the two or three seconds of sound immediately prior to cutoff. These segments of sound were the portions which were analyzed with regard to the vibrato rate and the vibrato extent. It was interesting, in regard to the frequency-variation type employed, to compare the final two-second segments of the sounds produced in each context by a given subject. These comparisons are summarized in Table VI.

TABLE VI

PATTERNS OF CHANGE (OR NO CHANGE) IN THE TYPES OF FREQUENCY
VARIATIONS EMPLOYED BY THE SUBJECTS IN SOLO SINGING
AND IN BLENDING SITUATIONS

Pattern of Frequency Variations Employed	Per Cent*
Vibrato used in both solo singing and blending . . .	60
Straight tone used in both solo singing and blending.	5
Nonperiodic variation used in both solo singing and blending.	2
Vibrato in solo singing; straight tone in blending.	17
Vibrato in solo singing; nonperiodic variation in blending	9
Straight tone in solo singing; vibrato in blending.	1
Straight tone in solo singing; nonperiodic vari- ation in blending	2
Nonperiodic variation in solo singing; vibrato in blending	1
Nonperiodic variation in solo singing; straight tone in blending.	4

*For each pattern of usage designated, the per cent of all the 450 pairs of sounds produced in both solo and blend contexts employing that pattern of usage.

There were no apparent differences in the frequency-variation types used at different pitch levels or on different vowels. In general, a greater variety of approach to frequency variations, regardless of the particular type, was observed among the sounds produced in blend context than among the sounds produced in solo context. This

aspect was observed for individual subjects as well as for the group of subjects as a whole.

Subjects who used straight tones or nonperiodic variations in solo context tended to do the same in blend context. However, while some of the subjects who used vibrato in solo context did the same in blend context, others experimented with different frequency-variation types over the duration of the sound. Some eventually settled on some pattern of vibrato, but others changed to straight tones or nonperiodic variations. As a group, singers who used vibrato in solo context exhibited greater variety in the types of frequency variations employed in blending than did singers who used straight tones or nonperiodic variations in solo context.

The majority of sounds sung in solo context were sung sharp with respect to the fundamental frequency of the pitch pipe on which the tones were sounded. Typically, the sharping was approximately 50 cents, but a sharpness of 100 cents or more was not unusual.

The sounds produced in blend context exhibited the trend toward sharpness also, but to a lesser degree than the sounds produced in solo context. The sounds produced in blend context also showed less variation among themselves with regard to deviations in frequency, and their fundamental frequencies tended to be closer to the correct frequency than the fundamental frequencies of the sounds

produced in solo context. The observations above applied to all vowels and pitch levels.

Discussions with the subjects, when they were shown graphs of their frequency-variation patterns some months after recording the sounds, indicated that most of them were unaware of their patterns of frequency variation in singing. Many were surprised to discover the rate and the extent of their vibrato patterns. It was also surprising to many to discover that they had produced straight tones or nonperiodic variations rather than patterns of vibrato.

Vibrato Rate

In both solo and blend contexts the vibrato rate was generally 5-6 oscillations per second, regardless of the vowel or the pitch level. The vibrato rate was usually slightly higher in solo context. Some group-mean differences were statistically significant while others were not. There were no clear patterns with regard to the vowel or the pitch level (see Table VII, page 80).

Vibrato Extent

For all vowels and pitch levels, the vibrato extent was slightly greater for the sounds produced in solo context than for the sounds produced in blend context. In solo context the vibrato extent was generally 60-80 cents, while in blend context the vibrato extent was generally 2-12 cents less. The group-mean differences were generally

TABLE VII

MEAN VIBRATO RATE* FOR GROUPS OF SOUNDS PRODUCED
IN SOLO AND BLEND CONTEXTS

Vowel	Pitch**	Context		t-Value	Degrees of Freedom	Probabil-ity***
		Solo (Vibrato Cycles per Second)	Blend (Vibrato Cycles per Second)			
[a]	C4	5.18	4.60	4.53	12	< .001
[a]	A4	5.35	5.14	2.07	20	.052
[a]	F5	5.39	5.28	.68	17	.503
[o]	C4	5.39	4.91	3.19	12	.008
[o]	A4	5.45	5.03	5.17	18	< .001
[o]	F5	5.41	5.24	1.32	16	.205
[e]	C4	5.13	5.01	1.33	11	.210
[e]	A4	5.37	5.11	2.45	20	.024
[e]	F5	5.49	5.27	2.51	15	.024
[m]	C4	5.15	4.92	3.49	18	.003
[m]	A4	5.46	5.01	4.03	20	< .001
[m]	F5	5.57	5.17	5.54	18	< .001
[i]	C4	5.21	4.90	4.10	17	< .001
[i]	A4	5.39	5.00	5.92	20	< .001
[i]	F5	5.46	5.12	4.20	19	< .001

*Rate: number of vibrato cycles per second.

**Pitch: C⁴ = 261 Hz., A⁴ = 440 Hz., F⁵ = 698 Hz.

***The probability of the difference between the means occurring by chance if no difference existed in the population means; calculated by a t-test of dependent means; group N = 30.

not statistically significant. There was no apparent pattern with regard to the vowel or the pitch level (see Table VIII).

TABLE VIII

MEAN VIBRATO EXTENT* FOR GROUPS OF SOUNDS PRODUCED
IN SOLO AND BLEND CONTEXTS

Vowel	Pitch**	Context		t-Value	Degrees of Freedom	Probabil-ity***
		Solo (Cents)	Blend (Cents)			
[a]	C4	74.54	65.77	.88	12	.397
[a]	A4	66.10	63.81	.42	20	.680
[a]	F5	63.22	55.06	1.39	17	.184
[o]	C4	83.31	59.00	2.55	12	.026
[o]	A4	74.89	64.58	2.02	18	.058
[o]	F5	59.47	55.94	.71	16	.486
[u]	C4	82.08	68.08	1.80	11	.100
[u]	A4	81.57	68.95	2.23	20	.037
[u]	F5	61.13	60.44	.16	15	.871
[e]	C4	73.68	61.74	1.39	18	.182
[e]	A4	75.33	59.10	2.56	20	.019
[e]	F5	75.84	61.00	1.55	18	.139
[i]	C4	75.39	62.67	1.40	17	.178
[i]	A4	73.95	63.43	1.44	20	.166
[i]	F5	68.15	58.40	1.82	19	.085

*Vibrato extent expressed in cents.

**Pitch: C⁴ = 261 Hz., A⁴ = 440 Hz., F⁵ = 698 Hz.

***The probability of the difference between the means occurring by chance if no difference existed in the population means; calculated by a t-test of dependent means; group N = 30.

Spectral Characteristics

The sonagrams revealed a clear pattern of difference in the spectral characteristics of the vocal sounds produced in solo and blend contexts. Although individual exceptions were observed, overall, the groups of sounds produced in each mode of performance exhibited the following differences

for all vowels and pitch levels: (1) a relatively unchanged, strong fundamental frequency or a slightly strengthened fundamental frequency in blend context, (2) a marked decrease in the relative amplitude of partials above the first formant in blend context, including to a lesser extent those partials comprising the second and third formants, and (3) mere traces of energy in the few partials above 5,000-6,000 Hz. among the sounds produced in both solo and blend contexts, with the exception of a few sounds in both contexts on the vowels [a] and [ɛ].

Spectral profiles comparing the sounds produced in solo and blend contexts are included in Appendix K. The profiles clearly illustrate the findings reported above. The single display shown in Figure 10, page 83, is typical. At the highest pitch level the minimal aural differences between the different vowels were reflected on the spectral profiles by relatively minimal visual differences between the different vowels.

The spectral profiles were based upon the group-mean values of the intensity ratings assigned to the different individual partials. These values were derived from visual analysis of each sonagram. The significance of the differences shown by the profile curves, therefore, rests on the extent to which the group-mean differences of the partials' intensity ratings were actual differences or were chance

differences, arising from the variability of the individual intensity values. In order to assess this aspect, t-tests of dependent means were used. The results of these t-tests are given in Appendix I.

Fig. 10--Spectral profiles showing typical differences between the spectral characteristics of vocal sounds produced in solo and blend contexts. The group profile of the sounds produced in blend context is distinguished by boxes placed at each plot-point, i.e., at each partial. The display above is for the pitch C⁴ (261 Hz.) and the vowel [i].

Above 5,000-6,000 Hz. the general lack of strong partials in sounds of either context made group-mean values miniscule and subject to disproportionate influence by

whatever small amounts of energy were present in that portion of the spectrum for only two or three sounds. As a result, the group-mean differences in the relative intensities of those partials above 5,000-6,000 Hz. are likely of little consequence.

Vowel Formants

The frequencies found for the first three vowel formants are shown in Table IX, page 85. The reported values represent the frequencies of the partials which were evidenced as center-points of energy concentration in approximately 80 per cent or more of the sounds. There did not appear to be uniform differences in the vowel formant frequencies of the vocal sounds produced in solo and blend contexts. Frequency differences that were observed usually involved high formants, specifically the third formant of any vowel or the second formant of [i]. In most cases those formants were slightly lower in frequency for the sounds produced in blend context.

The differences occurring most often between the vowel formants of the sounds produced in solo and blend contexts were differences of relative intensity. Specifically, the differences included a slightly increased strength in the first formants of sounds produced at the lowest pitch level in blend context and a greatly decreased relative amplitude of the second and third formants of the sounds produced at all pitch levels in blend context. The relative intensities

TABLE IX

VOWEL FORMANT FREQUENCIES FOR VOCAL SOUNDS PRODUCED
IN BOTH SOLO AND BLEND CONTEXTS*

Vowel	Pitch	First Formant		Second Formant		Third Formant	
		Partial Number**	Frequency (Hz.)	Partial Number	Frequency (Hz.)	Partial Number	Frequency (Hz.)
[ɑ]	F5	1	698	2	1396	4	2792
	A4	2	880	3	1320	7	3080
	C4	2	522	4	1044	12	3132
[o]	F5	1	698	2	1396	4	2792
	A4	1	440	2	880	8	3520
	C4	2	522	4	1044	11	2871
[u]	F5	1	698	2	1396	4	2792
	A4	1	440	2	880	6	2640
	C4	2	522	4	1044	10	2610
[ɛ]	F5	1	698	2	1396	4	2792
	A4	2	880	4	1760	6	2640
	C4	2	522	7	1827	10	2610
[i]	F5	1	698	3	2094	6	4188
	A4	1	440	5	2200	9	3960
	C4	1	261	9	2349	15	3915

*The reported values represent the frequencies of partials which were identified as center-points of energy concentration in approximately 80 per cent or more of the sounds.

**The number given refers to the nth partial in the vocal sound. Partial number one refers to the fundamental frequency. Formants occurred on differed numbered partials for sounds sung at different pitch levels.

of those partials identified as formant frequencies are shown along with the other partials of the spectra in Appendix I.

Comparisons of the group-mean intensity values of the vocal sounds produced in solo and blend contexts indicated no statistically significant ($p = .05$) differences for the first formants of any vowel at any pitch level. However, since the relative amplitudes of the second and third formants were greatly reduced among the sounds produced in blend context, the group-mean differences were statistically significant in each case.

Additional Observations

Almost all the singers reported having difficulty controlling their phonation at the lowest pitch level. For some singers, certain vowels seemed also to present more difficulty for phonation than other vowels, although there appeared to be no pattern concerning which vowel was the most difficult to sing.

The subjects reported having differing degrees of difficulty in achieving a good blend with the ensemble on different vowels and at different pitch levels. There appeared to be no consistent pattern with regard to which vowels or pitch levels presented the most difficulty, however.

One finding of the present study was only of curious interest to the study of vocal blend, but the finding is

reported for the possible interest of other investigators. Of the 900 vocal sounds analyzed spectrographically, 45 were found to have two pitches sounding simultaneously. On the sonagrams the phenomenon was evidenced by the presence of partials located at frequencies between the harmonically-related partials of the intended fundamental frequency (see Figure 11).

Fig. 11--Sonagram of a soprano vocal sound in which two pitches are being sung simultaneously. The partials appearing between the harmonically-related partials of the intended fundamental frequency can be seen extending across the sonagram at points indicated by the arrows.

When such an isolated vocal sound was heard, the two pitches generally were audible. Usually the added pitch was perceived an octave below the principal, intended pitch.

The double tones were observed as scattered occurrences in the vocal sounds of fifteen of the thirty subjects in the

study, but the characteristic was persistent among the sounds of only five subjects. There was no apparent pattern with regard to the vowel sung. There was a slight tendency for the double tones to occur more at the middle and upper pitch levels. The phenomenon was observed in about twice as many of the sounds produced in blend context as in solo context. Sounds containing double tones were found both among groups of sounds identified as blending well with the ensemble and also among groups of sounds identified as blending poorly with the ensemble.

The double tone phenomenon is described in the literature of speech pathology, where it is referred to by the term "diplophonia" (3, pp. 287-288). It is generally considered a vocal anomaly or a curiosity. Reportedly, some individuals are capable of producing double tones at will as a kind of trick. Elsewhere its cause is often attributed to unequal vibration modes of the two vocal folds, due to tumors, partial paralysis of certain vocal muscles, edema (swelling), excessive mucus, or improper coordination of the phonation mechanisms (1, pp. 183, 230; 2, pp. 73-74; 3, pp. 287-288; 4, p. 138).

Summary of Acoustical Qualities of Vocal Sounds Produced in Solo and Blend Contexts

The following list summarizes the findings regarding the acoustical qualities of vocal sounds produced in solo and blend contexts.

1. Overall intensity was greater for vocal sounds produced in solo context, the difference varying over a general range of 5-9 db and the magnitude of difference increasing with the pitch level.

2. The fundamental frequencies of sounds produced in solo context were, for approximately 90 per cent of the sounds, 25-75 cents higher than the appropriate fundamental frequency of the pitch pipe on which a given note was sounded.

3. Greater variety of frequency-variation types was observed among the vocal sounds produced in blend context than among the vocal sounds produced in solo context.

4. Vibrato rates were generally 5-6 oscillations per second in both contexts, often slightly higher for vocal sounds produced in solo context.

5. The fundamental frequencies of sounds produced in blend context often varied 25-50 cents from the target frequency. They were usually higher than the target frequency. However, the range of the singers' frequency variations about the target frequency was less for the sounds produced in blend context than for the sounds produced in solo context.

6. The vibrato extent typically was 60-80 cents for the sounds produced in solo context and approximately 2-12 cents less for the sounds produced in blend context.

7. The fundamental frequency was strong among the sounds produced in both contexts, sometimes stronger for sounds produced in blend context.

8. Partial above the first formant were weaker in relative amplitude for sounds produced in blend context than for sounds produced in solo context.

9. Partial above 5,000-6,000 Hz. generally were weak or missing for the sounds produced in both solo and blend contexts, except for a few sounds in both contexts on the vowels [a] and [ɛ].

10. The vowel formant frequencies were approximately the same for the sounds produced in both contexts, except for a few sounds produced in blend context, where the second formant of [i] and the third formants of all the vowels sometimes were slightly lower in frequency.

11. Typically, the first formants were approximately the same relative intensity for sounds produced in both contexts, sometimes slightly stronger for sounds produced in blend context.

12. The second formants were weaker in relative intensity among the sounds produced in blend context than among the sounds produced in solo context.

13. The third formants were weaker in relative intensity among the sounds produced in blend context than among the sounds produced in solo context.

Each of the findings above is discussed in Chapter V.

Acoustical Qualities of Vocal Sounds Identified
as Blending Well and Blending Poorly

Overall Intensity

For all vowels and pitch levels, the overall intensity at the time of recording was greater for sounds identified as blending poorly with the ensemble than for sounds identified as blending well with the ensemble. The difference was approximately 1-5 db at each pitch level. The group-mean differences were statistically significant for four vowels at the lowest pitch level and for one vowel at the middle pitch (see Table X, page 92).

Frequency-Variation Types Observed

Of the sounds identified as blending well with the ensemble, approximately 28 per cent had a pattern of vibrato from beginning to end; approximately 21 per cent had a straight tone pattern from beginning to end; and approximately 18 per cent had a nonperiodic variation pattern from beginning to end. The remaining 34 per cent of the sounds identified as blending well with the ensemble had two or more changes in the frequency-variation type over the sound's duration.

Of the sounds identified as blending poorly with the ensemble, approximately 68 per cent had a pattern of vibrato from beginning to end; approximately 6 per cent had a straight tone pattern from beginning to end; and approximately 9 per cent had a nonperiodic variation pattern from

TABLE X

MEAN OVERALL INTENSITY (DECIBEL LEVEL)^a OF GROUPS OF SOUNDS
IDENTIFIED AS BLENDING WELL AND BLENDING POORLY
WITH A UNISON ENSEMBLE

Vowel	Pitch ^b	Group ^c		t-Value	Degrees of Freedom	Probabil- ity ^d
		Good (Decibels)	Poor (Decibels)			
[a]	C4	69.71	76.50	-5.44	18	<.001
[a]	A4	76.82	80.44	-1.23	18	.242
[a]	F5	90.07	94.95	-1.86	18	.088
[o]	C4	70.94	72.42	-2.28	18	.035
[o]	A4	78.15	78.51	-0.20	13	.847
[o]	F5	91.04	95.59	-1.82	12	.094
[u]	C4	67.47	72.07	-5.37	18	<.001
[u]	A4	80.20	81.47	-0.71	18	.487
[u]	F5	92.29	94.11	-0.95	13	.361
[m]	C4	71.28	73.42	-1.77	18	.094
[m]	A4	73.89	79.07	-2.91	11	.014
[m]	F5	92.61	93.62	-0.45	18	.658
[i]	C4	68.09	71.11	-3.22	18	.005
[i]	A4	77.93	80.88	-1.98	18	.063
[i]	F5	89.29	92.15	-1.40	18	.179

^aDecibels with reference to .0002 dynes/cm².

^bPitch: C⁴ = 261 Hz., A⁴ = 440 Hz., F⁵ = 698 Hz.

^cGood = group of sounds receiving the highest third of the blend ratings; poor = group of sounds receiving the lowest third of the blend ratings; each group N = 10.

^dThe probability of the difference between the means occurring by chance if no difference existed in the population means; calculated by a t-test of independent means.

beginning to end. The remaining 10 per cent of the sounds identified as blending poorly with the ensemble had two or more changes in the frequency-variation type over the sound's duration.

As a group, those sounds identified as blending well with the ensemble exhibited greater variety in the types of frequency variations employed than did those sounds identified as blending poorly with the ensemble.

Vibrato Rate

Among both groups of sounds identified as blending well and poorly with the ensemble, the vibrato rate was generally 4.50-5.25 oscillations per second, regardless of the vowel or the pitch level. The comparison group having the slightly higher vibrato rate varied. None of the group-mean differences was statistically significant (see Table XI, page 94).

Vibrato Extent

For all vowels and pitch levels, the vibrato extent was greater for the groups of sounds identified as blending poorly with the ensemble than for the groups of sounds identified as blending well with the ensemble. The vibrato extent for the groups of sounds identified as blending poorly with the ensemble ranged approximately 59-78 cents. The vibrato extent for the groups of sounds identified as blending well with the ensemble ranged approximately 36-66 cents (see Table XII, page 95).

The group-mean differences ranged widely with different vowels and different pitch levels: from a difference of less than 1 cent on the vowel [u] at the middle pitch

TABLE XI

MEAN VIBRATO RATE^a FOR GROUPS OF SOUNDS IDENTIFIED
AS BLENDING WELL AND BLENDING POORLY
WITH A UNISON ENSEMBLE

Vowel	Pitch ^b	Group ^c		t-Value	Degrees of Freedom	Probabil- ity ^d
		Good (Vibra- to Cycles per Second)	Poor (Vibra- to Cycles per Second)			
[a]	C4	4.50 (N=4)	4.77 (N= 6)	0.72	8	.490
[a]	A4	5.28 (N=5)	4.96 (N=10)	1.48	13	.162
[a]	F5	4.88 (N=2)	5.22 (N= 8)	-0.93	8	.377
[o]	C4	4.50 (N=2)	4.94 (N= 8)	-2.31	7	.540
[o]	A4	5.27 (N=7)	5.05 (N= 8)	0.95	13	.360
[o]	F5	5.10 (N=4)	5.27 (N= 8)	-0.71	10	.495
[u]	C4	4.94 (N=4)	5.13 (N= 8)	-0.81	9	.439
[u]	A4	5.19 (N=6)	4.96 (N= 8)	1.17	12	.264
[u]	F5	5.32 (N=4)	5.11 (N= 7)	0.67	9	.518
[e]	C4	4.71 (N=6)	4.91 (N= 7)	-0.87	11	.405
[e]	A4	4.96 (N=7)	5.06 (N= 8)	-0.40	13	.695
[e]	F5	5.25 (N=5)	5.13 (N= 8)	0.55	11	.592
[i]	C4	4.53 (N=5)	5.06 (N= 8)	-1.61	11	.136
[i]	A4	5.07 (N=4)	4.95 (N=10)	0.42	12	.679
[i]	F5	5.11 (N=6)	5.00 (N= 7)	0.38	11	.713

^aRate: number of vibrato cycles per second.

^bPitch: C⁴ = 261 Hz., A⁴ = 440 Hz., F⁵ = 698 Hz.

^cGood = group of sounds receiving the highest third of the blend ratings; poor = group of sounds receiving the lowest third of the blend ratings.

^dThe probability of the difference between the group means occurring by chance if no difference existed in the population means; calculated by a t-test of independent means.

level to over 30 cents on the vowel [O] at the high pitch level. Group-mean differences were statistically significant

TABLE XII

MEAN VIBRATO EXTENT^a FOR GROUPS OF SOUNDS IDENTIFIED
AS BLENDING WELL AND BLENDING POORLY
WITH A UNISON ENSEMBLE

Vowel	Pitch ^b	Group ^c		t-Value	Degrees of Freedom	Probabil- ity ^d
		Good (Cents)	Poor (Cents)			
[a]	C4	49.50 (N=4)	78.50 (N= 6)	-1.76	8	.116
[a]	A4	45.80 (N=5)	75.10 (N=10)	-2.56	13	.024
[a]	F5	39.50 (N=2)	63.25 (N= 8)	-1.08	8	.313
[o]	C4	62.50 (N=2)	59.38 (N= 8)	0.13	8	.901
[o]	A4	50.71 (N=7)	76.63 (N= 8)	-2.86	9	.019
[o]	F5	36.50 (N=4)	67.00 (N= 8)	-2.60	9	.029
[u]	C4	44.50 (N=4)	73.38 (N= 8)	-2.10	9	.065
[u]	A4	66.17 (N=6)	67.00 (N= 8)	-0.06	12	.955
[u]	F5	49.25 (N=4)	64.00 (N= 7)	-1.01	9	.339
[e]	C4	59.50 (N=6)	66.00 (N= 7)	-0.39	11	.707
[e]	A4	53.71 (N=7)	77.25 (N= 8)	-2.83	10	.018
[e]	F5	55.60 (N=5)	74.00 (N= 8)	-1.72	11	.113
[i]	C4	47.00 (N=5)	66.88 (N= 8)	-1.27	11	.229
[i]	A4	49.25 (N=4)	75.40 (N=10)	-1.46	12	.169
[i]	F5	40.83 (N=6)	63.43 (N= 7)	-2.02	11	.068

^aVibrato extent expressed in cents.

^bPitch: C⁴ = 261 Hz., A⁴ = 440 Hz., F⁵ = 698 Hz.

^cGood = group of sounds receiving the highest third of the blend ratings; poor = group of sounds receiving the lowest third of the blend ratings.

^dThe probability of the difference between the group means occurring by chance if no difference existed in the population means; calculated by a t-test of independent means.

for three vowels at the middle pitch level and for one vowel at the high pitch level.

Accuracy of the Fundamental Frequencies

In both groups identified as blending well and blending poorly with the ensemble, the fundamental frequencies of the sounds showed variations about the target frequency. The fundamental frequencies of sounds identified as blending well with the ensemble varied in some cases as much as 100 cents above, or 50 cents below, the target frequency. The extent of such differences from the target frequency varied with different vowels and different pitch levels, but there appeared to be no pattern in this regard.

It was interesting to compare the sounds identified as blending well and blending poorly with the ensemble where both sounds exhibited the following characteristics in common: (1) the same frequency-variation type employed, i.e., both used vibrato, straight tones, or nonperiodic variations; (2) the same relationship of the fundamental frequencies to the target frequency, i.e., both fundamental frequencies were accurate or both were equally misaligned in the same direction from the target frequency; and (3) a comparable extent of the vibrato or of the nonperiodic variations.

In situations where the above characteristics were shared both by sounds identified as blending well and blending poorly with the ensemble, the poorly blending sounds were distinguished by one or more of the following features: (1) stronger and/or more numerous upper partials,

- (2) stronger and/or more numerous partials on frequencies lying between the first and second formants, and
- (3) stronger second and/or third formants.

In situations where the spectral characteristics were comparable and the relationships of the fundamental frequencies to the target frequency were comparable, the sounds identified as blending poorly with the ensemble generally were distinguished by a greater vibrato extent.

In situations where the spectral characteristics were comparable and the vibrato extent, or the extent of the nonperiodic variations, was comparable, the sounds identified as blending poorly with the ensemble were distinguished by their fundamental frequencies being located a greater distance from the target frequency.

It is evident that, for achieving good ratings of vocal blend, the importance of an individual sound having its fundamental frequency aligned with the target frequency was an aspect which was moderated by the spectral characteristics of the sound and its vibrato extent.

Spectral Characteristics

Overall, the sonagrams revealed a clear pattern of difference between the spectral characteristics of the groups of sounds identified as blending well with the ensemble and the spectral characteristics of the groups of sounds identified as blending poorly with the ensemble.

The groups were generally characterized by the following differences:

1. At the lowest pitch level the fundamental frequencies were stronger among the sounds identified as blending well with the ensemble than among the sounds identified as blending poorly with the ensemble.

2. At the middle and upper pitch levels the fundamental frequencies appeared approximately equal in relative intensity among both the groups of sounds identified as blending well with the ensemble and the groups of sounds identified as blending poorly with the ensemble. Among both groups the fundamental frequency appeared to be the strongest element in the spectral profile at the middle and upper pitch levels.

3. At the lowest pitch level the first formant was slightly stronger among the groups of sounds identified as blending well with the ensemble than among the groups of sounds identified as blending poorly with the ensemble. Among both groups the first formant, typically, appeared stronger than the fundamental frequency at the lowest pitch level.

4. The groups of sounds identified as blending well with the ensemble had less relative intensity in the partials above the first formant than the groups of sounds identified as blending poorly with the ensemble.

5. Above approximately 5,000 Hz. there appeared to be little significant energy present among either the groups of sounds identified as blending well with the ensemble or the groups of sounds identified as blending poorly with the ensemble.

Generally, it appeared that the spectral differences between the groups of sounds identified as blending poorly and blending well with the ensemble resembled, respectively, the spectral differences observed between the groups of sounds produced in solo and blend contexts.

Spectral profiles comparing the groups of sounds identified as blending well with the ensemble and the groups of sounds identified as blending poorly with the ensemble are included in Appendix L. The profiles clearly illustrate the findings reported above. The single display shown in Figure 12, page 100, is typical. At the highest pitch level the minimal aural differences between the different vowels were reflected on the spectral profiles by relatively minimal visual differences between the different vowels.

The spectral profiles were based upon the group-mean values of the intensity ratings assigned to the different individual partials. These values were derived from visual analysis of each sonagram. The significance of the differences shown by the profile curves, therefore, rests on the extent to which the group-mean differences of the

partials' intensity ratings were actual differences or were chance differences, arising from the variability of the individual intensity values. In order to assess this aspect, t-tests of independent means were used. The results of these t-tests are given in Appendix J.

Fig. 12--Spectral profiles showing typical differences between the spectral characteristics of vocal sounds identified as blending well with the ensemble and vocal sounds identified as blending poorly with the ensemble. The group profile of the sounds identified as blending well with the ensemble is distinguished by boxes placed at each plot-point, i.e., at each partial. The display above is for the pitch C^4 (261 Hz.) and the vowel [a].

Vowel Formants

There did not appear to be uniform differences in the vowel formant frequencies of the vocal sounds identified as blending well with the ensemble and the vocal sounds identified as blending poorly with the ensemble. Frequency differences that were observed usually involved high formants, specifically the third formant of any vowel or the second formant of [i]. In most cases those formants were slightly lower in frequency among the sounds identified as blending well with the ensemble than among the sounds identified as blending poorly with the ensemble.

The differences occurring most often between the vowel formants of the groups of sounds identified as blending well with the ensemble and the groups of sounds identified as blending poorly with the ensemble were differences of relative intensity. Specifically, the differences included a slightly increased strength in the first formants of some sounds produced at the lowest pitch level and a greatly decreased relative amplitude of the second and third formants at all pitch levels among the groups of sounds identified as blending well with the ensemble. The relative intensities of those partials identified as formant frequencies are shown along with the other partials of the spectra in Appendix J.

Comparisons of the group-mean intensity values of the vocal sounds identified as blending well with the ensemble

and the vocal sounds identified as blending poorly with the ensemble indicated no statistically significant differences for the first formants of any vowel at any pitch level. However, since the relative amplitudes of the second and third formants were greatly reduced among the groups of sounds identified as blending well with the ensemble, the group-mean differences were statistically significant in many cases.

Additional Observations

Individual subjects varied considerably in their approaches to blending. A few used thorough, methodical approaches, while others appeared to use random or arbitrary approaches. While some subjects sang a sound and then altered it to blend, others first listened closely to the ensemble and apparently decided beforehand what kind of sound to employ. Approached in the latter way, such sounds tended not to change their acoustical characteristics greatly over their duration.

Some individuals concentrated almost wholly on one or two aspects, such as overall intensity or vibrato, while others seemed to be concerned with several aspects of the sound. Of the latter group, some subjects employed vocal changes in a predictable order, e.g., overall intensity first, vibrato second, and vowel quality next.

The length of time that notes were held during a given attempt to blend with the ensemble varied over a

range of 2-24 seconds. The duration of most sounds was in the range of 4-10 seconds. Individual subjects tended to be rather consistent with themselves in this regard.

The vowels receiving the highest ratings of blend were in order: [O], [u], [i] or [a], and [ɛ]. This pattern was generally consistent at all pitch levels. Additionally, the same order of vowels according to their ratings of blend was observed among both groups of sounds identified as blending well with the ensemble and blending poorly with the ensemble.

The order of vowels according to their ratings of blend corresponded generally to the inverse order of the vowels by the number of partials present in the sound. The vowels consistently receiving the highest ratings of blend were those having the least number of partials, e.g., [O] and [u]. Conversely, the vowel consistently receiving the lowest ratings of blend was the one having the greatest number of partials, e.g., [ɛ].

There seemed to be no analogous pattern of order with regard to the pitch level and the blend ratings which different sounds received. However, the variation in blend ratings between different vowels was greatest at the low pitch level and least at the highest pitch level. That is, the lower the pitch level, the greater the variation which existed among the different vowels on the blend ratings they received. The higher the pitch level, the smaller

the variation which existed among the different vowels on the blend ratings they received.

Summary of Acoustical Qualities of Vocal Sounds
Identified as Blending Well and
Blending Poorly

The following list summarizes the findings regarding the acoustical qualities of the vocal sounds identified as blending well and blending poorly with the ensemble:

1. Overall intensity often was greater for the groups of vocal sounds identified as blending poorly with the ensemble than for the groups of vocal sounds identified as blending well with the ensemble. The differences varied over a range of 1-5 db, the magnitude of difference being slightly greater at the lowest pitch level.

2. The alignment of the vocal sounds' fundamental frequencies with the target frequency did not differ greatly between the groups of sounds identified as blending well with the ensemble and the groups of sounds identified as blending poorly with the ensemble. The importance of this factor appeared to be moderated by an individual sound's spectral characteristics and vibrato extent.

3. Greater variety of frequency-variation types was observed among the vocal sounds identified as blending well with the ensemble than among the vocal sounds identified as blending poorly with the ensemble.

4. The vibrato rates were generally 4.50-5.25 oscillations per second for both groups of sounds identified as

blending well and blending poorly with the ensemble. There appeared to be no practical differences between the two groups.

5. The vibrato extent ranged 40-66 cents for the groups of sounds identified as blending well with the ensemble and 59-78 cents for the groups of sounds identified as blending poorly with the ensemble. The group-mean differences varied from 1-30 cents and usually were not statistically significant.

6. The fundamental frequencies were approximately the same relative amplitude among both the groups of sounds identified as blending well and blending poorly with the ensemble, except at the lowest pitch level, where the fundamental frequencies tended to be slightly stronger among the groups of sounds identified as blending well with the ensemble. For both groups, the fundamental frequency tended to be weaker than the first formant at the lowest pitch level. At the highest pitch level the fundamental frequency appeared to be the strongest element in the spectral profile for both groups.

7. Partial above the first formant were weaker in relative amplitude among the sounds identified as blending well with the ensemble than among the sounds identified as blending poorly with the ensemble.

8. Partial above 5,000-6,000 Hz. generally were weak or missing for both groups of sounds identified as blending well and blending poorly with the ensemble.

9. The vowel formant frequencies were approximately the same for both groups of sounds identified as blending well and blending poorly with the ensemble, except for a few sounds identified as blending well with the ensemble, where the second formant of [i] and the third formants of all the vowels sometimes were slightly lower in frequency.

10. The first formants typically were approximately the same relative intensity for both the groups identified as blending well and blending poorly with the ensemble, sometimes slightly stronger for the groups of sounds identified as blending well with the ensemble.

11. The second formants were weaker in relative intensity among the groups of sounds identified as blending well with the ensemble than among the groups of sounds identified as blending poorly with the ensemble.

12. The third formants were weaker in relative intensity among the groups of sounds identified as blending well with the ensemble than among the groups of sounds identified as blending poorly with the ensemble.

Each of the findings above is discussed in Chapter V.

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CHAPTER V

DISCUSSION AND INTERPRETATION OF THE FINDINGS

The results reported in Chapter IV indicated that the groups of sounds identified as blending poorly with the ensemble differed acoustically from the groups of sounds identified as blending well with the ensemble in similar ways as the sounds produced in solo context differed acoustically from the sounds produced in blend context. For this reason, it seems appropriate to discuss the findings of both major areas of the study together.

Complexity of the Vocal and Aural Processes

Obviously, it would be desirable to provide definitive answers--to explain in simple, unequivocal terms how singers alter their sounds to achieve vocal blend. An equally clear-cut view of the manner in which specific acoustical changes affect the perceived vocal blend would also be desirable. However, an awareness of the complexities inherent in the vocal and aural processes quickly dims hopes for simple answers.

For example, consider the interrelated functions of the different laryngeal muscles which are primarily

responsible for each of the aspects of pitch, loudness, and timbre:

The cricothyroid influences pitch and vocal register. The vocalis participates in regulating pitch, intensity, register, and the onset of the voice. The lateral cricoarytenoid participates in regulating pitch, intensity, register, and the onset of the voice. The interarytenoid has a less significant role in regulating the acoustic parameters of the voice. The posterior cricoarytenoid is usually inactivated during phonation, but it contracts to some extent for high tones in heavy register to brace the arytenoid cartilage against the anterior pull (20, p. 43).

The different muscles of the vocal mechanism work together so much like a unit that it is virtually impossible for one to operate independently of another. Thus, a vocal modification intended primarily to change the sound in one way may change it in several ways. In a situation where a singer intentionally alters her sound in order to blend, it is difficult to determine with confidence which aspects of the sound the singer primarily intended to alter. There are further difficulties in speculating how that specific acoustical properties of a vocal sound might affect a listener's perception of the vocal blend.

What the listener perceives upon hearing a sound does not correspond one-to-one with the acoustical characteristics of the sound stimulus.

. . . loudness depends principally upon the intensity, but changes in the frequency or the overtone structure may sometimes produce large changes in loudness. Also, the pitch depends principally upon the frequency, but changes in

the intensity produce small changes in the pitch and certain types of changes in the overtone structure may produce large changes in pitch. And finally, the timbre depends principally upon the overtone structure, but large changes in the intensity and the frequency also produce changes in the timbre (12, p. 68).

The sound reaching the listener is modified first by the resonance characteristics of the listener's ear. Next, the mechanical properties of the ear's moving parts affect their patterns of vibration (33, pp. 281-282). Finally, more changes occur as the vibrations are transformed into coded information in the form of nerve impulses and sent to the brain. Minifie refers to these listener-induced changes as "distortion products," and he indicates that their effects on the sound which the listener perceives are unknown (33, pp. 281-282).

Despite the acknowledged difficulties, however, a logical unraveling of the intertwined complexities appears possible. But the nature of the vocal and aural processes, in effect, confines interpretation to suggesting plausible explanations rather than providing definitive answers.

The aims of the following discussion are: (1) to assimilate the various findings of the present study, (2) to consider those findings in conjunction with relevant concepts from studies in the fields of vocal acoustics and aural perception, and (3) to demonstrate how the resulting synthesis helps to explain the phenomenon of vocal blend.

Overall Intensity

The ability to produce vocal sounds of great intensity has been shown to be a common attribute of concert singers (4, pp. 26-27) and an important objective of vocal pedagogy (1, p. 19). On the other hand, choral directors have been almost unanimous in agreement that choral blend is adversely affected by individual voices singing with a large overall intensity (16, pp. 9-13).

Common experience attests that loud singers "stick out." Even Aristotle, commenting on chorus members in Greek dramas, remarked:

. . . no one by differing from the rest would render himself conspicuous by making himself heard above the rest (41, p. 933).

Obviously then, it seems reasonable to explain some of the intensity differences observed in the present study on the basis that the singers were striving not to be conspicuously loud amid the ensemble sound. How much this was a factor is not clear.

It is difficult to estimate how precisely a subject might have been able to evaluate her own intensity changes as she heard her voice along with the ensemble. The extent of intensity change which is just noticeable with sine tones under the most favorable laboratory conditions is approximately 1 db (2, p. 85). In the present study the subjects were monitoring their own intensity changes under conditions considerably less favorable for discriminating

fine levels of difference. In addition, they were monitoring intensity changes occurring in complex tones rather than in sine tones, as is typically the case in laboratory settings.

The ensemble, which was sounding continuously in the singer's ears, represented a source of constant and irregular fluctuation of intensity, ranging from 1-5 db. It appears that this was due to the constantly varying sum of the intensity vibrato of each singer in the ensemble. A typical range of fluctuation for an individual singer's intensity vibrato is 1-3 db (45, p. 72). It seems a reasonable assumption that intensity changes over time occurred slightly differently for the intensity vibrato of each singer in the ensemble and that mutual reinforcement of one another's momentary intensity levels occurred by coincidence.

Viewed in this perspective, an intensity difference of 5-6 db between a vocal production intended for solo singing and another vocal production intended for achieving maximum vocal blend does not seem exceptionally large. That is not to say, however, that the singer attempting to blend did not perceive a large difference in the loudness of her solo and blending efforts.

Perceived loudness is dependent on several factors in addition to intensity (12, p. 68). The distinction must remain clear between intensity as a physical characteristic

of the sound stimulus and loudness as a psychological attribute of the listener's sensation. Some of the acoustic and perceptual factors possibly influencing the perceived loudness of the blending singers' own voices will be discussed in later areas of this chapter.

It seems possible that in some instances singers may have reduced their overall amplitude in order to reduce the masking effect of their own voices on the ensemble. Theoretically, this would have enabled them to hear more clearly the sound of their own voices combined with the ensemble and thereby to enhance their ability to discriminate any details in the sound which may have prompted vocal adjustments in order to blend.

It appears, however, that the matter of a singer's reducing the overall intensity of her sound in order to achieve vocal blend is not wholly explained on the basis of intended loudness differences alone. The present study indicated that a number of other acoustical changes occurred in parallel with changes of overall intensity. The effect that such parallel acoustical changes may have had on the perceived vocal blend may further account for the observed differences of overall intensity between the vocal sounds produced in solo and blend contexts.

An important acoustical change accompanying intensity change involves the glottal spectrum. This is the acoustic waveform generated by the larynx before the sound is

influenced by resonance changes imparted by passage through the vocal tract. Increased vocal intensity occurs through increased subglottic air pressure and increased tension of the vocal folds (63, p. 204; 9, p. 63). This results in the glottis being closed for a longer period of time during each vibratory cycle. The subglottic air pressure is thereby permitted to build up longer, resulting in a more powerful burst by the air puff emitted when the glottis finally opens (9, p. 63). (See Figure 13.)

Fig. 13--Laryngeal vibratory cycles at weak and loud intensities (54, pp. 11-19).

Acoustically, the result of increased vocal intensity is a glottal spectrum in which each partial is almost equal in intensity. By contrast, vocal sounds of low intensity have a glottal spectrum in which the fundamental frequency is the strongest element and each successive partial weaker (5, pp. 368-369). In both cases the spectral envelope of

the sound transmitted at the mouth opening corresponds to a particular glottal spectrum additionally shaped by the resonance curve of the vocal tract (5, p. 370). (See Figure 14.)

Fig. 14--Schematic representations of sound production in speech. The air pressure variations initiated at the glottis (a) are passed through the vocal tract (b) and are radiated from the mouth as a complex wave (c). Viewed in terms of spectral events, the glottal spectrum consists of harmonically-related partials whose amplitude decreases with each successively higher partial (d). The resonating characteristics of the vocal tract (e) modify the glottal spectrum so that certain partials in the glottal spectrum are reinforced while others are damped. The radiated acoustic wave (f) is thus dependent upon both the glottal spectrum and the transfer function of the vocal tract (8, p. 19).

In the present study the sounds produced in blend context, as well as the groups of sounds identified as blending well with the ensemble, exhibited timbre changes along with reductions of overall intensity. Typically, the changes

were toward stronger fundamental frequencies and fewer and/or weaker upper partials. Such changes may have been achieved in some instances by changes in the glottal spectrum, induced by decreases in overall intensity. In such cases, the intensity changes may have served intentionally as means for changing vocal timbre as well as loudness.

Several studies tend to support this possibility. Scott (43), using female voices, demonstrated that as the overall intensity of a vocal tone increases, the number and strength of upper partials also increases. Conversely, as the overall intensity of a vocal tone decreases, the number and strength of the upper partials decreases, the uppermost partials disappearing first.

Since the number and relative amplitude of upper partials tends to decrease as vocal tones are sung with decreased intensity, a question could be raised concerning the reduced amplitude of the upper partials observed among the groups of vocal sounds produced in blend context and among the groups of vocal sounds identified as blending well with the ensemble. Specifically, could the spectral change have occurred as a result of the singers' producing the sounds in blend context at a lower level of overall intensity rather than as a result of direct, intentional changes to the spectra in efforts to achieve vocal blend?

This matter was taken into account at the outset of the study, when the possibility of controlling the overall

intensity at the same level for the pairs of sounds produced in both solo and blend contexts was considered. That approach was not adopted because it would have placed unnatural restraints on the singers.

If the subjects had been required to employ the same overall intensity for the vocal sounds produced in solo context as employed for the same vowel and pitch level in blend context, then the singers may have been hindered from producing vocal sounds typical of their solo singing. On the other hand, if the subjects had been required to employ the same overall intensity in their attempts to blend with the ensemble as they employed in producing vocal sounds representative of their solo singing, then the singers may have been unnecessarily restricted in their blending efforts and forced to adopt approaches to blending with the ensemble which they might not ordinarily have employed. Therefore, the singers were given freedom to employ whatever levels of overall intensity they regarded as appropriate for the vocal sounds produced in the contrasting performance situations.

Moreover, it was assumed that with 450 pairs of sounds produced in solo and blend contexts, a fair sample of the pairs would show comparable levels of overall intensity for corresponding sounds produced in both contexts by the same singers, thus providing the opportunity to observe possible spectral differences where no appreciable differences of

overall intensity were present. This assumption proved to be correct.

Of the 450 pairs of sounds produced in solo and blend contexts, 22 per cent showed an intensity difference of ± 2 db or less. This difference seemed to represent a figure well within the margin of reporting error in reading the SPL meter, and, therefore, about as close as it would have been possible for a subject to duplicate a previous intensity level.

Of the sounds showing an overall intensity difference of ± 2 db or less between solo and blend contexts, about 75 per cent exhibited the pattern of reducing the number and relative amplitude of the upper partials in blending. There were fourteen pairs of sounds for which the intensity was greater in blend context than in solo context. Of these, more than two-thirds showed the same pattern of reducing the number and relative amplitude of the upper partials in blending.

The evidence thus suggests that reductions in overall intensity for sounds produced in blend context contributed to reductions in the number and relative amplitude of the upper partials, but that the same pattern of spectral change tended to occur in those instances where the overall intensity was unchanged or even greater for the vocal sounds produced in blend context.

There are yet other possible explanations for the subjects reducing their overall intensity in blending. It has been observed that "oversinging," i.e., singing with too great an intensity for the voice, can result in "spreading," which is an undesirable vowel quality in singing (55, p. 204). Vennard has shown by means of sonagrams that spreading is characterized acoustically by partials of significant energy appearing at frequencies between the formants, particularly above the second formant (see Figure 15, page 151).

Similar characteristics were observed in the present study for some vocal sounds identified as blending poorly with the ensemble and for some sounds produced in solo context. Since the detrimental effects of spreading and certain other defects of timbre (e.g., breathiness) may often be remedied by reducing the overall intensity (55, p. 204), it appears possible that some singers may intuitively have decreased their overall intensity in order to improve their vowel quality, thereby enhancing their vocal blend.

At areas near points of transition from one vocal register to another, singers often are capable of producing tones in either vocal register. Such tones have been studied by Large, who has called them "isoparametric" tones (25, p. 12). It has been recognized that singing with too great an intensity may cause the chest or middle

register to be carried higher and employed for singing tones which would be more efficiently produced in the next higher register (55, pp. 66-67, 196). Voice teachers sometimes refer to this as "forcing." It has been shown that, acoustically, forcing results in an increase in the upper partials of a tone (55, p. 169). It appears that the frequency of the sung tone and, possibly, its subjective pitch may be affected by forcing.

Register transitions were observed occurring during the course of some tones sung in blend context. The timbre differences before and after register changes were audible and were also visible on sonagrams made of such sounds in their entirety. Thus, the lower intensity levels typically employed by the subjects in blend context may partly be explained on the basis that the singers in some instances were seeking to remedy the adverse effects on the vocal blend of forcing.

Another factor which may be affected by changes in overall intensity is the sonance quality associated with the intensity vibrato. Sonance refers to the perceptual fusion of successive changes in a sound over time, the result being interpreted by the listener as affecting tone quality. For example, a sine tone having a vibrato appears to have a different tone quality than an unmodulated sine tone, even though the spectral characteristics are the same. Sonance is thereby distinguished from timbre, where perceived

differences in tone quality occur primarily in response to changes in a sound's spectral features, i.e., perceptual fusion of acoustical components sounding simultaneously (44, p. 103).

Vocal sounds of greater intensity may be characterized by wider ranges of fluctuation of the intensity vibrato, thereby causing changes in those sounds' sonance characteristics. Although equipment for charting the sounds' intensity vibrato was not available for the present investigation, some pertinent observations were made.

As a part of the training which the subjects received in reading the SPL meter, they were asked to sing tones at various levels of intensity and to report the decibel level to the researcher, who was looking on. It was observed that loud sounds often showed intensity variations ranging 3-5 db over each vibrato cycle. When the overall amplitude of such a sound was reduced, however, the range of intensity over each vibrato cycle typically was reduced to approximately 1 db or less.

It appears, therefore, that the level of overall intensity in singing may affect the extent of the intensity vibrato. The extent of the intensity vibrato, in turn, may affect a tone's vocal blend. Theoretically, vocal blend would be affected adversely by a large extent of the intensity vibrato, due to the prominence such a characteristic would give an individual vocal sound.

It has been shown that the perceived pitch of a tone having a frequency vibrato may be affected by the magnitude of parallel fluctuations of intensity (53, p. 200). The possible effects which an intensity vibrato may have on a tone's sonance qualities and on its perceived pitch imply that certain related characteristics could function as aural cues for making an individual voice prominent amid an ensemble sound. Thus, the singers attempting to achieve vocal blend may have reduced their overall intensity partly in order to reduce the extent of fluctuation of the intensity vibrato, thereby reducing any adverse effects of its associated characteristics on the vocal blend.

It may be recalled that the group-mean intensity levels were consistently higher for the groups of sounds identified as blending poorly with the ensemble, but that the group-mean differences were not statistically significant except for four vowels at the lowest pitch level and one vowel at the middle pitch level. This indicated that the variation among the different singers on their intensity levels was generally so great that the differences in their group means could easily have occurred by chance.

Even in those instances where the group-mean differences were statistically significant there were situations where that individual vocal sounds identified as blending well with the ensemble had greater levels of overall intensity than some of their counterparts identified as blending

poorly with the ensemble. As might be expected, the same situation occurred more often among sounds where the group-mean differences were not statistically significant.

The results above tend to rule out overall intensity as a single, overriding factor differentiating the groups of sounds identified as blending well with the ensemble from the groups of sounds identified as blending poorly with the ensemble. The evidence suggests that overall intensity was but one of the contributing factors affecting a given sound's blend with the ensemble.

Separating the causes from the effects in matters relating to acoustical changes associated with changes of overall intensity may be impossible. As Luchsinger and Arnold have noted, ". . . the physical magnitudes of subglottic air pressure, vocal sound pressure, and tonal pitch are interrelated in a very complicated manner" (30, p. 92).

Types of Frequency Variations

There are several implications of the finding that greater variety of frequency-variation types (vibrato, straight tones, and nonperiodic variations) was observed among the vocal sounds produced in blend context and among the groups of sounds identified as blending well with the ensemble than among their counterparts.

First, most subjects apparently perceived the need to explore more of the options for frequency variations available to them when seeking to achieve a vocal blend than

when singing in a manner representative of their solo singing. This is further indicated by the apparent trial-and-error nature of certain frequency changes in some sounds produced in blend context over the duration the tones were held. The evidence suggests that the subjects did perceive that certain changes of vibrato and frequency affected their blend with the ensemble. This merely provided tangible evidence for what was apparent already from common experience.

Second, the individuals most successful at blending apparently explored more of the frequency-variation options available to them than did individuals who were less successful at blending. This may mean that certain individuals were more sensitive to the influence of frequency changes on their blend with the ensemble or that such individuals were more adept in their vocal control.

Third, the fact that different approaches to vibrato and voice frequency were employed with success by different individuals implies that no singular approach was required in order to blend.

Why certain approaches were favored over other options available is not always clear. In some instances a given singer's approach may be explained as a manifestation of the approach normally employed by that individual in solo singing. For example, subjects who used straight tones or nonperiodic variations in solo context usually did the same

when trying to blend with the ensemble. Similarly, several subjects who used vibrato in solo context exhibited the same characteristics of vibrato when singing in blend context. Such observations as those above do not, however, necessarily constitute evidence that usage of particular frequency-variation types or particular vibrato characteristics provided an advantage for achieving vocal blend with the ensemble.

On the other hand, certain patterns of change in the frequency-variation characteristics of pairs of sounds produced in solo and blend contexts appeared to offer clues concerning the advantage of certain approaches for achieving blend with the ensemble. For example, subjects who produced sounds in solo context with a rather large vibrato extent typically altered their vibrato extent appreciably when attempting to blend with the ensemble. By contrast, subjects who produced sounds in solo context with a small vibrato extent typically altered their vibrato extent little, or none at all, when attempting to blend with the ensemble.

There were aspects other than pitch-related concerns that may have been factors explaining such changes in the vibrato characteristics of certain sounds. For example, the magnitude of vibrato extent permissible for sounds identified as blending well with the ensemble appeared to

be related to the number of upper partials present in the sound.

In order to provide a logical explanation for why certain approaches to frequency-variation type, vibrato characteristics, and voice frequency were adopted by certain individuals in attempting to blend, it was found helpful to consider all, or some, of the other acoustical features present in a given sound, e.g., its spectral qualities and its overall intensity. When an individual vocal sound was considered as a "package" of acoustical features and was viewed in the light of certain acoustical and perceptual concepts, logical patterns in the usage of certain frequency-variation characteristics and other acoustical qualities began to emerge.

There is evidence suggesting that there is an interrelationship between a vocal tone's pitch-related characteristics (e.g., its vibrato) and its spectral features, making it advantageous for the singer to adopt mutually beneficial approaches to both factors in order to achieve vocal blend. The nature of this interrelationship is such that it can best be understood only when certain aspects of vocal acoustics and aural perception are both taken into account. Therefore, this matter is explained later in the sections of this discussion which are devoted to vibrato and to spectral characteristics and also in a separate area of discussion devoted to the matter alone.

Vibrato Rate

The concept that a vocal tone's vibrato rate may be affected by its overall intensity is suggested by two principles: (1) the intensity of a sung tone is partly a function of the amount of subglottic air pressure used in phonation (63, p. 204; 9, p. 63), and (2) vibrato is influenced (although not necessarily caused) by changes of subglottic air pressure (26, p. 46; 64, p. 25; 58, p. 258).

Large has shown that a relationship exists between airflow rates and vibrato. Specifically identified were differences in airflow rates between vibrato and straight tone singing (26, p. 46).

In a study reported in 1953 Winckel found an increase in vibrato rate associated with the singing of a crescendo and a decrease in vibrato rate associated with the singing of a diminuendo (59, p. 232). Seashore reported similar results in 1938 (44, pp. 35-38). The finding was again confirmed by Winckel in a recent study (1974), in which it was also reported that the relationship between changes in vocal intensity and vibrato rate varied with the different singers observed (58, p. 258). The variableness of the relationship between vocal intensity and vibrato rate is demonstrated by Sjostrom's report of finding no difference in vibrato rate between loud and soft singing (47, p. 93).

Winckel, referring to vibrato rate, alluded to other possible contributing factors:

The process may be further disturbed because the singer constantly corrects the pitch of his output by ear, in order to exert a continuous influence on the muscles adjusting the pitch (58, p. 258).

Winckel's observation implies that a singer's vibrato rate may be affected in some instances because the singer controls his vocal pitch by listening to it. It has been noted that, by concentrating upon certain features of the sound, singers may affect aspects of their sounds which ordinarily are not under conscious control (1, pp. 232-233). It may be possible that by directing thought toward one's own vibrato, as when carefully noting its effect upon one's vocal blend, the vibrato rate, which tends to establish itself without need for conscious control, may tend to slow somewhat. This, of course, is merely speculative, but appears to be a possible explanation for the finding of the present study that vocal sounds produced in blend context tended to have slower rates of vibrato than vocal sounds produced in solo context.

Easley found that subtle changes of vibrato were associated with certain types of singing. Specifically, it was found that the same performers used faster and wider vibrati in operatic areas than in concert songs. Easley concluded that the differences arose because ". . . such vibratos are adequate to achieve the effects required in these songs" (7, p. 273). The higher vibrato rates observed among vocal sounds produced in solo context may

partly be explained on a similar basis, i.e., that some subjects responded intuitively to singing in different musical contexts by employing subtle differences of vibrato rate.

The general pattern of a slightly slower rate of vibrato in blend context seems to indicate at least a mild degree of association between the vibrato rate and the context in which the vocal sounds were produced. However, only a few group-mean differences of vibrato rate between groups of sounds produced in solo and blend contexts were statistically significant. The lack of a clear pattern of association between the vibrato rate and a certain vowel or pitch level precludes a definitive explanation for the above finding.

Possible explanations include chance, or, perhaps, the particular vibrato characteristics of the ensemble on certain sounds. Another possibility lies in the fact that the statistical comparisons of vibrato rate between contexts required the use of paired values (32, p. 114). Thus, values of vibrato rate from individuals not using vibrato in both contexts for a given sound were categorically excluded in computing group means for purposes of statistical comparison. Perhaps combinations of circumstances, such as those previously mentioned in this discussion, contributed to statistical significance in some cases. In practical terms, it does not appear that the slightly

different rates of vibrato would sound appreciably different.

Pitch Alignment

It was not unexpected to find that the singers' fundamental frequencies were closer to the target frequency when the singers produced sounds in blend context than when they produced sounds in solo context, even though sounds produced in both contexts tended to be sharp. In solo context a singer's pitch reference, or target pitch, had to be the perceived pitch of the tone sounded by the pitch pipe, as remembered by the singer. By contrast, the singer's target pitch in blend context was the perceived pitch of the ensemble, a sound which was supplied continuously to the singer's ears. When attempting to blend, the singer had a constant pitch reference, against which she could continuously compare her own production and made necessary corrections. Thus, the fundamental frequencies of sounds produced in blend context were closer to the target frequency and varied less in range among themselves.

A similar finding was reported by Papich and Rainbow, who found that string players playing identical passages in solo and group situations played slightly closer to the correct frequency (i.e., less sharp) when performing with the group (34, p. 38).

There is a prevailing idea among choral directors that accurate alignment of the vocal pitches is crucial for vocal

blend (16, pp. 9-13). It has been proposed that, theoretically at least, the greatest accuracy of alignment can be obtained by tones sung without vibrato (51, p. 19). However, vibratoless singing is not allowable in many instances for reasons of stylistic propriety, feared harm to the vocal instrument, or personal preference and taste (3, pp. 19-21).

The compromise typically suggested is to encourage singers to restrict the extent of their vibrati within reasonable limits, which satisfy both the requirements of pitch accuracy and the remaining criteria (3, pp. 19-21). The validity of that practice, in terms of its effectiveness for achieving vocal blend, as well as the question of pitch alignment, are matters which may be verified, at least in part, by examining certain results of the present investigation.

At the outset of this phase of the discussion it may be important to point out that voice pitch, a subjective quality, was not measured in this study. Rather, it was the objective frequency of the fundamental (or the first partial above the fundamental frequency in some instances).

In order to have assessed vocal pitch in terms of a tone corresponding to a particular frequency, it would have been necessary to present a given vocal pitch to a group of subjects and have them adjust a variable-frequency reference tone until a satisfactory correspondence of the perceived pitches was obtained (38, p. 116).

It has been found in similar experiments that pitch perceptions for the same sound stimulus vary among different subjects, and even among the same subjects at different times (2, p. 112). Hence, pitch perception experiments have required calculating and reporting some average frequency as corresponding to the pitch perceived (38, p. 103).

While appearing superficially, perhaps, to be a mere technicality, the possible difference between a vocal tone's fundamental frequency and its perceived pitch may be an important consideration in explaining why certain tones in the present study were rated higher in blend than certain of their counterparts whose fundamental frequencies lay closer to the target frequency.

For reasons which will become increasingly apparent, it is yet undetermined how adequate the procedure is whereby vocal pitches are evaluated solely by examining charts of their fundamental frequencies. Retaining this aspect in mind, consideration of the matter of pitch alignment may proceed.

Since the members of the ensemble employed moderate degrees of vibrato, it seems a reasonable assumption that all of them never sang precisely the same fundamental frequency, except for mere fractions of a second as their individual frequency oscillations happened to cross one another. This idea is supported by sonagrams of the ensemble showing the individuals' different vibrato

patterns in the upper partials, where the extent of the vibrato oscillations was more visible than at the fundamental frequency. However, not one time was it mentioned by any subject that the target pitch of the ensemble was unclear. There is a logical explanation for this.

It has been proposed that a listener's aural perception mechanism, in evaluating oscillating tones for their pitch, fuses the successive oscillations which are heard, and through a process of normal illusion, such as occurs with the visual sense, perceives a pitch which almost as clear as a single unmodulated tone (46, p. 370). That proposition is supported by the results of this study, in that it may explain why the perceived pitch of the ensemble was not ambiguous to the subjects attempting to blend with it.

It is interesting to speculate on the finding that the vocal sounds produced in solo context consistently had a larger vibrato extent than their counterparts in blend context. The tendency persisted, even though the large amount of variation among the different sounds produced in both contexts resulted in no statistical significance of the group-mean differences in most cases.

If it is true that a wide vibrato extent renders the perceived pitch ambiguous, thereby preventing its accurate alignment with other tones and adversely affecting the vocal blend, then it would be expected for the present study to

show that sounds with a wider vibrato extent were consistently rated lower in blend. Although the results tended in that direction, such was not always the case.

The mean vibrato extent was always larger for the groups of sounds identified as blending poorly with the ensemble than for the groups of sounds identified as blending well with the ensemble, but the group-mean differences were statistically significant in less than a third of the cases. The variation among the different singers was so great that the group-mean differences could be attributed to chance in the majority of cases.

This is further supported by the fact that in numerous instances individual sounds were assigned higher blend ratings than other individual sounds having a smaller vibrato extent. This seems to indicate that other factors in addition to vibrato extent were affecting the blend. A possibility immediately coming to mind would be that the poorly blending tones were sharp or flat, i.e., misaligned with regard to the target frequency.

If it is true that an accurate alignment of different tones' fundamental frequencies is a necessary condition for them to blend well together, then it would be expected for the present study to show that individual sounds whose fundamental frequencies differed from the target frequency, i.e., were misaligned, were consistently rated lower in

blend. The results indicated that this was not always the case.

It was found that the fundamental frequencies of sounds identified as blending well with the ensemble varied in some instances as much as 100 cents above or 50 cents below the target frequency. Interestingly, for a given vowel and pitch level, most of the sounds identified as blending poorly with the ensemble lay well within the frequency band spanned by the sounds identified as blending well with the ensemble.

Given the usual assumptions made by choral directors regarding the relationship between vocal pitch and choral blend, it is difficult to explain the acceptability of such large apparent misalignments of pitch. An initial reaction to the findings above might be to conclude, tentatively at least, that vocal pitch is not so important a factor in choral blend as commonly thought. While that indeed may be a possibility, it so contradicts such a widely accepted belief that more critical examination seems in order.

An assumption apparently underlying this line of reasoning is that the fundamental frequency of a vocal tone corresponds exactly to the perceived vocal pitch. It has been shown that the presence of a fundamental frequency in a complex tone is not required in order for a clear pitch to be perceived (13, p. 437). Spectrographic analysis has revealed that a fundamental frequency, although it is

perceived by the listener, is not always present in a sung tone (36, p. 377). If the frequency of the fundamental as the determinant of a vocal tone's pitch is questioned, what elements in the sound do determine the pitch? For the moment, the effect of vibrato on the perceived vocal pitch will be set aside, although the issue will be considered later.

It is the prevailing view that the pitch of a complex tone is determined by the common repetition rate of the partials (40, pp. 135-136). This is sometimes called periodicity pitch. For example, a complex tone having a fundamental frequency of 250 Hz. will have harmonic partials lying essentially at integral multiples, i.e., 500 Hz., 750 Hz., 1000 Hz., 1250 Hz., and on upward in a similar manner. The common repetition rate, or pattern of frequency spacing between the partials, is 250 Hz., the same as the fundamental frequency. The perceived pitch of the sound then corresponds to a frequency of 250 Hz., more or less.

This appears to bring the matter back to where it began. For, if the common repetition rate of a tone's partials corresponds to the frequency of the fundamental, why could not the fundamental frequency be taken as equal to the perceived pitch?

The difference lies in the dependence of periodicity pitch on the relationships between the partials. These relationships may be affected by such factors as the number

of partials in the sound, the frequency range in which certain partials are located, the distribution of relative amplitude among the partials, the steadiness of the overall amplitude, the steadiness of the amplitude of the individual partials, the nature of the tone's frequency components (e.g., whether they consist of sine tones, or perhaps, closely spaced groups of sine tones), and possibly other factors (50, pp. 17-34).

There is evidence concerning the effect of some of these features on a tone's perceived pitch, but the information is far from complete. Fletcher found that three consecutive, harmonically related partials were sufficient to give a clear musical tone with a pitch equal to the pitch of a simple tone of what would be the fundamental frequency (13, pp. 427-437).

Ritsma determined that, for a complex tone having a fundamental frequency lying in the range 100-400 Hz., the spectral region dominant for the perception of pitch corresponded to a frequency band encompassing the third, fourth, and fifth partials (39, p. 197).

Plomp found that, for complex tones having fundamental frequencies up to 350 Hz., the pitch was determined by the fourth and higher partials. For complex tones having fundamental frequencies on up to 700 Hz., the pitch was determined by the third and higher partials (35, p. 1526).

Studies of the pitch of complex tones, such as the studies just mentioned, typically have controlled the various acoustical factors carefully. For example, sine tones have been employed for the frequency components. The overall intensity has been held constant. The amplitude of each partial has been held steady. A fixed distribution of relative amplitude among the partials has been maintained, and other factors have been similarly controlled (50, pp. 17-34).

Contrast, however, the acoustical characteristics of the sounds used in studies of periodicity pitch with the acoustical characteristics of sung tones. Benade indicates that there is an inherent unsteadiness of the vocal fold motion due to inescapable muscle tremor and to aerodynamic instabilities of the airflow. This produces slight fluctuations in the amplitudes and frequencies of each partial in the vocal spectrum (5, p. 386).

. . . each unsteady partial is in fact a closely spaced clump of randomly arranged steady sinusoids; the strongest members of these clumps have very nearly the nominal frequency of the partial, with weaker components being spread over a narrow surrounding region of frequency. For some voices, each of these narrow-band clumps of sound is spread across a pitch range of about 15 cents; for others it is as narrow as 5 cents (5, p. 386).

Benade notes that, by contrast, the partials of instrumental tones typically consist of single-component, or sine, tones. Additionally, sonagrams from the present study show that in some cases the sounds sung by soprano voices may

have only one or two partials above the fundamental frequency. Where vibrato is present in a sung tone, the intensity of different partials may fluctuate greatly during phases of each vibrato cycle, even to the point of appearing to switch on and off (55, p. 193).

The differences between the kinds of tones used in previous studies of periodicity pitch and the tones produced by singers, particularly sopranos, raise serious questions concerning how prevailing theories of periodicity pitch may apply to the perceived pitch of certain vocal tones. In turn, questions are raised regarding how the pitches of tones sung in the present study were perceived and how the vocal blend was affected.

The pitch perception mechanism may be more discriminating in judging the pitch of sounds rich in upper partials than sounds having few upper partials. Such a view is consistent with findings from studies of pitch perception comparing pure tones with complex tones. In a study concerned with the influence of intensity on pitch Fletcher concluded that sounds rich in partials have greater stability against pitch fluctuation than sounds poor in partials (14, p. 215). This would partly explain a finding in the present study that where two tones were equally sharp or flat and one was identified as blending well with the ensemble and the other identified as blending poorly with

the ensemble, the latter invariably had stronger and more numerous upper partials.

The possible effect of upper partials on pitch perception might also to some degree account for differences among vowels in the readiness with which they blend. Previous studies as well as the present investigation have indicated that vowels containing few partials, such as [ʊ], have consistently received higher ratings of blend than vowels containing many upper partials, such as [ɛ] (21, p. 96; 18).

A contributing factor concerning the possible effect of pitch alignment on vocal blend may be the peculiar feature of voices pointed out by Benade, that the partials of sung tones resemble clumps of sine tones extending across a band 5-15 cents in extent. It has been observed that the spread of approximately 20 cents in the frequency components of violin tones permits them greater pitch deviations in performance (5, p. 549). Presumably, the same sort of pitch liberties may apply to vocal tones as well.

The effect that partials have on pitch apart from their effect on timbre (assuming the effects can be separated) has been the subject of several studies (12; 35; 22; 27; 28; 56). As Ward has pointed out, however, ". . . the meager evidence is ambiguous" (56, p. 427). Clearly, the matter concerning the perceived pitch of vocal tones is a subject requiring further research.

Vibrato and Vocal Pitch

Tiffin conducted a series of studies on vibrato. His findings with regard to the perceived pitch of a tone having vibrato are generally consistent with the results of the present study. Tiffin's conclusions, as summarized by Seashore, are presented in the following discussion.

The pitch of the frequency vibrato is localized slightly below the mean frequency, the amount of the flattening being roughly proportional to the extent of the vibrato (46, p. 214).

This tends to agree with the present finding that the mean fundamental frequencies of the sung tones were above the target frequency in the majority of cases.

When the extent of the vibrato is increased to between .75 and 1.00 step, the pitch is localized very far from the mean frequency, sometimes higher and sometimes lower.

The pitch of a vibrato up to a half-step in extent is localized practically as definitely as the pitch of a tone of constant frequency. As the extent of the vibrato is increased beyond a half-step the localization becomes less definite (46, p. 214).

The ideas above are consistent with the wide range of acceptable fundamental frequencies (judged from the mean frequency of the oscillations) which were present among the groups of sounds identified as blending well with the ensemble.

The perceived pitch of a frequency vibrato is raised by the addition of a parallel fluctuation in energy and lowered by the addition of an opposite fluctuation in energy (46, p. 214).

This concept may help explain the present finding that vocal tones with greater overall intensity were consistently rated lower in blend. The presence of a prominent intensity vibrato in loud tones produced by the subjects was noted earlier. The same principle may also have been a contributing factor in some subjects reducing their overall intensity when attempting to blend.

Vennard reported an unpublished study by Makepeace (31) concerning the perceived pitch of tones using vibrato. Subjects were presented an electronically produced vibrato whose characteristics were carefully controlled. They were asked to tell which of several unmodulated pitches matched that of the vibrato. The median pitch was chosen as the pitch of the vibrato by all the subjects. In a second phase of the study subjects were told that the vibrato contained both a high and a low tone, and they were asked to identify them. They selected pitches around whose frequencies the upper and lower loops of the vibrato hovered (55, p. 199).

In another study Kuttner proposed that the perceived pitch corresponds to the lower excursion of the frequency oscillations of the vibrato (24, pp. 372-374). Ward, however, discounted the idea (56, p. 423).

A study by Ward in 1954 and another by Fletcher et al. in 1965 suggested that the scales of both performers and listeners were tuned sharp (57, pp. 369-380; 15, pp. 851-863). The latter study suggested that the optimum strategy

for producing vibrato would be for the tones to oscillate about a frequency slightly higher than the one established by the physical scale. Using this performance practice, the mean frequency of the vibrato oscillations would be 15-20 cents sharp with regard to the target frequency (56, p. 424).

In a study reported in 1974, Papich and Rainbow observed a tendency toward sharpness in the playing of string performers (34, p. 38).

The findings of the above studies concerning an apparently natural preference for a slight sharpness may account in part for the tendency toward sharpening which was observed for the majority of tones in the present study.

The variety of accuracy in the alignment of the fundamental frequencies of the groups of sounds identified as blending well with the ensemble may be explained in part by a concept proposed by Kock. In a study in 1936 Kock expressed the idea that an interval would be acceptable if the vibrato excursions merely included the frequency that the listener considered to be correct:

Thus a note originally off pitch may be made acceptable by imparting a frequency vibrato to it, provided the intended pitch is included in the vibrato interval and provided the vibrato interval is not too wide to be objectionable (23, p. 24).

It may be noteworthy that none of the studies discussed thus far concerning the perceived pitch of tones

using vibrato reported using complex tones as opposed to sine tones for their investigations. The acoustical differences between vocal tones using vibrato and the carefully controlled electronic tones typically used in studies of vibrato perception add further to the questions raised earlier concerning the acoustical differences between sung tones and tones used in investigations of periodicity pitch.

In 1970, Ward, at the end of a review of research studies concerned with pitch perception, stated that there was ". . . little evidence to indicate just what pitch the listener hears in a tone with vibrato" (56, p. 423). Specifically, the following questions point up the present lack of information available for explaining in confident terms the relationships between pitch, vibrato, and vocal blend.

What happens to the perceived vocal pitch where there are only the first two or three partials in the tone? Where the partials consist not of sine tones but of clumps of closely spaced sine tones extending across a band 5-15 cents wide? Where the distribution of relative amplitude among the partials is not equal? Where the amplitudes of different partials may fluctuate in intensity, some perhaps decreasing as others are increasing, even to the point of appearing to switch on and off? Where each partial oscillates up to 4 per cent in frequency and at a rate of 5-6 cycles per second? Where a vocal tone is evaluated for its pitch while being heard amid a group of other complex

tones exhibiting similar, but not identical, characteristics?

It appears that there is presently no conclusive evidence to indicate exactly how the perceived pitch of a vocal tone, especially one sung by a soprano voice and employing vibrato, is related to the tone's fundamental frequency.

There are explanations concerning the possible roles which vibrato may play in vocal blend which place less emphasis on the contribution of vibrato to a tone's perceived pitch. Because a vocal vibrato involves periodic variations that are coherent for all the harmonic components of a tone, the vibrato may supply a "timing cue" which a listener's auditory processing mechanism uses in "locking in" and singling out a specific sound source, e.g., an individual singer amid an ensemble (40, p. 146; 5, p. 548).

It has been proposed that such a process accounts for the ability of a listener to discriminate the individual qualities of simultaneously sounding tones (40, p. 146). Examples of this ability include a listener's being able to single out different instruments playing simultaneously in an orchestra. Presumably, the infinitesimal time differences in which sounds from different sources reach the ears, in conjunction with other cues which are uniquely coherent for a given sound, e.g., vibrato, pitch, and timbre, are used by the perception mechanism for attributing the sensations to a single source.

It has been suggested that the same processing mechanism enables a listener to disentangle individual sounds from among the mixture of superposed sounds in a reverberating room, the so-called "cocktail party effect" (40, p. 146).

Although the matter obviously requires further research for verification and for refinement of the concepts, there is a remarkable similarity of the tasks just described to the task of the listener in discriminating individual vocal sounds in an ensemble. Interestingly, it may be the objective of the singer attempting to achieve an ensemble blend to "fool" the listener's auditory processing mechanism in such a way that a single sound source, the ensemble as a whole, is perceived. If true, this would imply that the singer's task in blending involves eliminating or minimizing the aural cues which the listener might use to identify the existence of a separate sound source.

Spectral Characteristics

There has been disagreement among the choral profession concerning whether individual modifications of vowel quality or vocal timbre are required in order to achieve vocal blend. Most directors, it appears, agree that the character of the vowel is important in the blend process. Some directors, however, recommend changes of vocal timbre, while others do not (62, pp. 135-136). The situation is complicated by the apparent fact that what some directors

regard as vowel modifications, other directors seem to regard as timbre modifications.

Since both vowel quality and vocal timbre are related to the relative strength and distribution of the partials in a tone, there is a sense in which the concepts are overlapping. However, distinctions have been made. Appelman has observed that identifiable acoustical differences in vocal performance can result, depending on the kind of understanding the singer or voice teacher has with regard to differentiating between vowel quality and vocal timbre (1, pp. 232-233). Some clarification of these concepts, as they pertain to vocal blend, may be provided by examining certain results of the present study.

It was reported in Chapter IV that, for vocal sounds produced in blend context and for sounds identified as blending well with the ensemble, the first formant appeared to be the most prominent feature of the spectral profile and also that the partials located between the formant frequencies were reduced significantly in relative amplitude.

At the middle and upper pitch levels the prominence of the first formant over the second and third formants appeared to occur primarily from amplitude reductions of the second and third formants rather than from a special strengthening of the first formant. At the lowest pitch level the first formant appeared to be specially

strengthened in addition to the amplitude reductions of the second and third formants.

Possible explanations for these findings lie in the concepts that each formant makes a somewhat different contribution to the perceived vowel quality and musical timbre and that the roles of the partials lying within the formant regions differ from the roles of the partials lying outside, or between, the formant regions. For identifying these differences, information drawn from studies of vowel sounds in speech as well as in singing appear potentially helpful. This approach has a number of research precedents.

Helmholtz discussed the acoustical correlates of vowel quality and musical timbre in much the same terms (19, p. 103). Stumpf compared the formants of musical instruments with those of vowels (48, p. 89). In a more recent investigation Slawson studied both vowel quality and musical timbre as functions of the spectrum envelope. He based his study on the claim that an investigation of musical timbre was properly begun with a study of speech sounds. His finding of certain parallels and ". . . similar functions of the relevant acoustic variables . . ." was submitted as supporting evidence for his initial claim (49, p. 100).

In the investigation of both speech sounds and musical sounds it has been reported that there are two ". . . humps in the integrating envelope . . ." of the spectrum which are important in the recognition of tone color (53, p. 15).

These humps correspond to the first two formants in the sound. Potter has proposed that the brain, in order to differentiate a sound, may scan the spectral envelope as if following along the outline with a pencil (37, p. 528) (see Figure 16, page 157). For finer differentiation, however, many other factors also have been considered important, e.g., the onset transients, formant frequency changes occurring over time, loudness, pitch, and other aspects (60, p. 15).

Wolf et al. explained how the function of partials lying within the formant peaks of the spectral envelope may differ from the function of partials lying outside the formant peaks.

Only a few frequencies are necessary to determine a vowel although the other partials which are present must modify the impression created, i.e., impart such characteristics as "brilliance," "shrillness," etc. It may be possible to consider that frequencies outside the vowel bands determine vowel "timbre," whereas variation in relative levels of the partials within the bands determine merely the vowel (61, p. 262).

The concept that each formant makes a somewhat different contribution to the perceived vowel quality and musical timbre is supported by the results of a study by Slawson. It was found that changes in the third and higher formant frequencies resulted in only slight differences in the perceived vowel quality or musical timbre, whereas even small changes in the first or second formants resulted in large

differences in the perceived vowel quality or musical timbre (49, p. 101).

The idea that the first formant may play a special role in speech sounds is contained in the report by Winckel that for some vowels, notably [μ], [O], and [Å], ". . . the second formants are of very slight intensity" (60, p. 13). Flanagan has stated that ". . . most of the sound energy of a vowel usually is contained in the first formant . . ." (10, p. 534).

Spectrographic studies of the singing voice have revealed that various types of poor vowel quality or vocal timbre tend to be associated with spectral envelopes in which the second or third formants are emphasized at the expense of the first formant. In a study of vocal timbre in male voices Gunn (18) found the following. "Spread" quality was characterized by an inordinate shift of formant two toward a higher frequency position. "Head" quality, as opposed to "normal" quality, was characterized by a greater bandwidth of formants two and three. "Nasal" quality was characterized by a reduction in intensity of formant one, combined with an increase in the formant bandwidth (18, p. 3885).

Vennard stated: "Those who get high partials at the expense of low ones are guilty of 'white' production. The French expression, 'voix blanche,' carries this connotation"

(55, p. 151). Speaking of the soprano voice in particular, Vennard asserted:

"Whiteness" is her besetting sin; she is unlikely to get any tones too "deep." This will be true of the vowels [i] and [e]. The upper formant will be safely out of her reach, but is likely to sound so strongly that they will be strident or shallow. It is more necessary for her to round her lips over these sounds, and to relax her jaw, than it is for other singers. The lowest formant she can get will be the fundamental itself, and she should "let it out" to offset the high formant, and round her lips to muffle high partials (55, p. 159).

By means of sonagrams Vennard demonstrated that "spread" quality in comparison with "normal" quality was characterized by the presence of greater energy in the upper partials and on partials between the vowel formants (55, p. 152). (See Figure 15.)

Fig. 15--Spectral differences of "spread" quality (left) and "normal" quality (right). The latter shows that the partials lying between the formant regions are greatly reduced in relative amplitude (55, p. 152).

Wolf et al. produced spectral profiles of vocal sounds identified as being of various qualities, e.g., "good," "poor," "normal," "white," and "nasal." It was shown that for baritones singing [A] on middle C, "poor" vocal quality was distinguished by a prominence of the second formant over the first. Similarly, in comparisons of "normal" quality and "white" quality, the latter was distinguished by a shift of both the first and second formants to higher partials, by the second formant being stronger than the first formant, and by the partials located between the first and second formants being strong relative to the formants themselves (61, p. 264). "White nasal" quality was distinguished by the practical elimination of the first formant and a shift of most of the energy to the second formant (61, p. 262).

The studies above seem to indicate that in singing it is desirable for the sake of vowel quality that the first formant be the most prominent feature of the spectral envelope. A further indication is that the prominence of partials located between the first and second formants is detrimental to vowel quality.

These ideas are consistent with the concept reported earlier that the first formant apparently has a special significance in speech communication. These observations also complement the finding of the present study that the vocal sounds identified as blending well with the ensemble were generally characterized by a spectral envelope in which

the first formant was strong relative to the second and third formants, and the relative amplitude of partials located between the formant peaks was weak.

A synthesis of the foregoing findings suggests that a singer, attempting to achieve vocal blend by modifying the vocal quality, may adjust the controlling aspects of vocal production (respiration, phonation, and resonation) to emphasize those partials whose prominence most defines the vowel, i.e., the vowel formants, particularly the first formant, and to minimize those partials which contribute least to the vowel's identity. The result may be a more "pure" vowel. As a part of this process, eliminating the "unnecessary" partials, i.e., partials lying between formant peaks and other partials whose effect is inconsistent with the "color" established by the spectral profile of the vowel formants, may then result in complementary changes of vocal timbre.

Viewed in the above manner, the technique of modifying the vocal quality for purposes of choral blend resembles Appelman's approach for training solo singers. Appelman's approach involves the use of recorded model-vowels, whose phonemes singers strive to match until they are aware of the manner in which their resonators are positioned to produce the particular vowel sounds.

If the singer concentrates upon timbre, he impairs the integrity of the vowel. If he concentrates upon the phoneme, he enhances the timbre (1, p. 232).

Quality thus becomes a result of and not the cause of the vocalic utterance (1, p. 233).

Thus, it appears that disputes among choral directors concerning whether vowel changes or timbre changes should be the primary means of access to choral blend may in some instances reflect differences of semantics as much as approach.

The results of this study support the concept that vowel modifications which are effective for achieving choral blend primarily involve changes in the intensity relationships among the vowel formants rather than changes of the vowel formant frequencies. The latter changes are not ruled out. Indeed, the sonagrams indicated that some changes in the positions of the second and third formants occurred in some instances. However, in the overwhelming majority of cases, the formant differences observed between the sounds produced in solo and blend contexts and between the groups of sounds identified as blending well and poorly with the ensemble involved differences in the relative intensity of the formants with regard to each other.

This view represents a somewhat different, though not necessarily contradictory, concept of vowel modification in choral blend from those expressed in other reports. Hunt, whose study of choral blend was discussed earlier in Chapter II, expressed the idea that vowel unity in choral sound was a matter of ". . . intonation of vowel formant frequencies" (21, p. 101).

Hunt's sonagrams were of male and female voices singing the same vowel sounds an octave apart and performing a C major scale. The sounds of various choirs were judged on their blend, and certain sounds were identified as having good or poor blend. Sonagrams of the different sounds were prepared.

The choral sounds having poor blend were characterized by wide energy concentrations at the partials and dark areas between many adjacent partials. By contrast, the choral sounds having good blend were characterized by narrow energy concentrations at the partials and relatively "clean" areas between most of the adjacent partials. Hunt concluded that the spectrographic differences were evidence that the groups producing the choral sounds having good blend had a common alignment of their individual vowel formant frequencies, whereas the other groups of individuals did not.

In connection with the present study, additional sonagrams were made of certain individual vocal sounds combined with the ensemble (rather than isolated from the ensemble). These sonagrams indicated that sonagraphic displays such as Hunt observed can result when one or more of the following conditions occur: (1) the fundamental frequency of an individual singing with the ensemble differs significantly from the fundamental frequencies of the ensemble singers, (2) an individual employs an unusually wide vibrato extent, especially in combination with strong upper partials,

(3) an individual produces sounds having unusually strong second or third formants, and (4) an individual singing with the ensemble produces sounds having particularly wide formant bands.

Hunt had no way to assess either the pitch, the vibrato, or the spectral characteristics of the individual singers apart from the choir as a whole. Thus, his conclusion was a logical one, if, perhaps, somewhat incomplete, in the absence of acoustical data on individual singers. It appears likely that vocal sounds having identical formant frequencies may have different vowel qualities if the individual sounds have significant differences in the distribution of relative amplitude among the formants, or if in some sounds there is significant energy on partials located between the vowel formant frequencies.

If, as suggested by Potter (37, p. 528) and others, vowel sounds are differentiated by a perceptual process in which the spectral envelopes are scanned by the brain, then the amplitudes of the formants, relative to one another, must be taken into consideration as well as the formant frequencies. The shape of the spectral envelope is a function of both frequency and intensity. This is illustrated by Figure 16, page 157, where spectral envelopes having the same formant frequencies, but different relative amplitudes, are readily differentiated visually.

Fig. 16--Spectral envelopes (after Winckel), each showing two formant peaks (60, p. 15). In each display the formant frequencies are the same, but the intensities of the formants relative to one another are different. The visual differences of the two spectral envelopes are readily apparent and suggest that the vowels they represent would also have aural differences which would be readily apparent.

The idea that the intensities of the formants, relative to one another, as well as the formant frequencies affect the perceived quality of a vowel is supported by studies reported by Flanagan (11, p. 280). The studies were concerned with determining how great a change in a vowel formant's intensity was required before a change was perceived in the vowel quality. For the second formant, the just noticeable difference was found to be approximately 3 db, whereas for the first formant the figure was only approximately 1.5 db (11, p. 280). This indicates that even small changes in the intensity of a vowel formant can result in perceived differences of vowel quality.

The results of the present study thus suggest that vowel modification, which is effective for achieving vocal blend, consists of changing the shape of the spectral

envelope so that the first formant is the most prominent feature and so that the other formant peaks are differentiated by the presence of minimal acoustical energy in the frequency regions between the formant peaks.

The Third Formant

A separate area of discussion has been reserved for the third formant because of its special significance for the singer. The spectral envelopes of sounds produced by operatic singers show a peak of energy in the region of 3,000 Hz. This spectral peak is present regardless of the pitch, the vowel, or the dynamic level. It has come to be considered a criterion of quality and has been designated the "singing formant." Located above the frequencies of the two lower vowel formants, the singing formant accounts for the "ring" of operatic voices and is thought to be the acoustic result of a lowered larynx (52, pp. 84-89).

The desirability of the singing formant has been explained as being related to the acoustical environment in which opera and concert singers perform: competition with an orchestra. The average distribution of energy in orchestral sounds shows the highest level in the vicinity of 450 Hz., above which the amplitude decreases sharply with frequency. The same general pattern is true of normal speech. A singer producing similar patterns of spectra would be at a great disadvantage in making himself heard above the orchestra's much stronger sounds. However,

because of the singing formant, the average sound distribution of a trained singer differs from that of an orchestra (52, pp. 88-89). (See Figure 17.)

Fig. 17--The long-time-averaged spectrum for an orchestra with and without a singer (5, p. 379).

Sundberg has explained the result of the singing formant:

Not only is the formant almost invariably audible, because its frequency is in a region where the orchestra's sound is rather weak, but also it may help the listener to "imagine" he hears other parts of the singer's spectrum that are in fact drowned out by the orchestra (52, p. 88).

The results of the present study indicated that singers attempting to blend reduced significantly the relative amplitude of partials above the first formant. This

included the second formant and the third, or singing, formant. However, while their relative amplitudes were reduced, the second and third formants were not eliminated altogether. Examination of the spectral profiles for all groups of sounds produced in the context of blending revealed an energy peak in the region near 3,000 Hz.

There are several possible explanations for the subjects' reducing the relative amplitude of the third formant in their attempts to blend with the ensemble. The usual function of the singing formant as an aid for making a singer prominent amid competing sounds would be unnecessary, and, possibly, even counterproductive, in a choral blend situation. The secondary function of the singing formant as a criterion of vocal quality would not be altogether lost if it were reduced in relative amplitude. As Coffin has pointed out, the singing formant does not have to be particularly strong because the ear is especially sensitive at that frequency (6, p. 39).

Bartholomew has indicated that generally the greater the intensity of a sung tone, the more prominent the singing formant becomes (4, p. 28). Logically then, the less the intensity of a sung tone, the less prominent the singing formant becomes. Reducing overall intensity as one means for achieving choral blend has already been discussed. It appears possible that the reduction of overall intensity of

the sounds produced in blending may have induced reductions in the relative amplitude of the third formant.

The presence of the third formant in combination with a wide vibrato extent can cause prominent partials in the vicinity of 3,000 Hz. to switch on and off with each vibrato cycle (see Figure 18, page 167). This phenomenon is discussed in a later section. Such a condition could conceivably be detrimental to a tone's vocal blend and may further explain why the singers in the present study tended to reduce the third formant's relative amplitude in the interest of achieving blend with the ensemble.

Effect of the Critical Bands

The critical band phenomenon may be a factor which may further explain why the number and relative amplitude of the upper partials were reduced in sounds produced in blend context and among the groups of sounds identified as blending well with the ensemble.

A technical account of the phenomenon is beyond the scope of this report, but in essence it has been shown that the auditory system responds to sounds in a manner in which the overall frequency-range of hearing is, in effect, divided into approximately two dozen smaller frequency ranges, called critical bandwidths (46, p. 162). There are several practical effects arising from this manner of response.

It has been demonstrated that the total loudness of a sound depends not only on the overall intensity of the sound, but also on the frequency range over which the frequency components, or partials, of the sound are distributed (48, p. 557). The greater the range over which the frequency components are spread, the more critical bandwidths are encompassed, and the greater the subjective loudness which the listener assigns to the sound. For example, if two tones have equal overall sound pressure levels, but the partials of one tone are distributed across a wider range of frequencies, thereby encompassing more critical bandwidths, the broad-band sound will be judged as the louder of the two (5, p. 245).

It can be seen that by removing some of the partials from a complex tone, the range of frequencies encompassed by the partials of the tone could be reduced, resulting in the tone having a lower subjective loudness, due to the critical band phenomenon.

The subjects in the present investigation, when attempting to blend with the ensemble, produced sounds having fewer partials than tones which they produced in a manner representative of their solo singing. Spectral patterns in which there were few upper partials also characterized the groups of sounds identified as blending well with the ensemble. Theoretically, reducing the number of partials in a tone would account for some reduction in the

perceived loudness of the tone, in addition to any decrease of loudness occurring in response to a decrease in the overall sound pressure level. Conceivably, such a reduction of loudness could provide some advantage for blending with an ensemble.

It has been shown that significant changes of perceived loudness can occur when there is a change in the distribution of relative intensity among the partials of a complex tone, even if no partials are eliminated (5, p. 245). Thus, some spectral changes employed by the singers in attempting to blend may have occurred partly because of the resulting differences such spectral changes caused in the perceived loudness of their tones.

The critical bands may also play a role in the perceived timbre of a complex tone. It has been shown that each of the first half-dozen partials of a tone lies within its own critical bandwidth and, resultingly, is processed for loudness as an individual frequency component, whereas the spacing of higher partials relative to the critical bandwidths is such that groups of higher partials are processed together (5, p. 548). Benade has shown that, as a consequence of the aspect just described, a harshness of tone can result if the higher partials are too strong relative to the lower half-dozen partials (5, p. 548). Winckel, speaking of vocal sounds, asserted, "The beauty

of a tone depends on the limitation of the partials" (60, p. 141).

The feature of the critical band phenomenon described above may also help to explain why sounds which received the highest ratings of blend had less relative amplitude in their upper partials than sounds which received the lowest ratings of blend.

Interaction of Vibrato and Spectral Features

When vibrato is employed in a tone sung in the soprano range, an interaction between the vibrato and the spectrum of partials occurs which may influence the characteristics of the vowel, the timbre, the sonance, and the perceived loudness of a tone. Changes in any of these aspects may affect a given tone's vocal blend with an ensemble.

A tone sung with vibrato is characterized by oscillations in each of its partials as well as in the fundamental frequency. Since the partials are essentially integral multiples of the fundamental frequency, an oscillation of 5 Hz. in the fundamental frequency will result in a 10 Hz. oscillation in the partial immediately above the fundamental frequency, a 15 Hz. oscillation in the next higher partial, and a similar pattern of oscillation for the higher partials. Each successive partial is characterized by an increasing extent of oscillation. It can be seen that for high partials, the extent of frequency oscillation

throughout the duration of a vibrato cycle can amount to several hundred Hz. (see Figure 18, page 167).

The extent of oscillation of a given partial depends on the frequency of the fundamental, the number of the partial in the numbered order of partials above the fundamental frequency, and the extent of the vibrato oscillations. Thus, the frequency oscillations are most pronounced for upper partials, for partials of tones sung on high pitches, and for tones sung with a large vibrato extent.

For tones sung in the middle or upper soprano range, a situation can occur where a formant frequency lies between two adjacent partials. When vibrato is employed on such a tone, the oscillations of the partials may carry them alternately closer to the formant frequency and farther away from the formant frequency during opposite phases of each vibrato cycle. As a partial moves closer to the formant frequency during one phase of the vibrato cycle, the partial is increasingly reinforced. Conversely, as a partial moves farther away from the formant frequency during the opposite phase of the vibrato cycle, the partial is increasingly damped.

The strength of these partials thus fluctuates predictably several times a second at the rate of the vibrato. The spectral envelope contains momentary peaks at the formant frequency as the partials move alternately in and out of the area of resonance (5, p. 385).

In situations where the partials are sufficiently far apart that none of them coincides exactly with a formant frequency, the listener may still be supplied with information concerning the shape of the spectral envelope, specifically, that the spectral envelope slopes toward a peak at a frequency between certain adjacent partials. The listener's auditory mechanism may then put this information together to resolve the ambiguity of the vowel, which might otherwise exist (5, p. 385).

It can also be seen that the effects noted above would be, theoretically, subject to change, depending on the vowel, the pitch level, the extent of the vibrato, the particular formant frequency involved, and the relative amplitude of the partials in the glottal spectrum.

The implication for vocal blend is that a vocal tone's vibrato causes intensity fluctuations in some partials and thereby alters the vocal timbre at a rate corresponding to the vibrato rate. These rapid changes over time may alter the sonance characteristics of the sound and could, conceivably, affect the perceived vocal blend. Logically, the effect of a tone's vibrato extent on its sonance would be less with a smaller vibrato extent and also less for vowels in which the first and second formants were low in frequency, e.g., [ʌ] and [ɔ]. It was found that these two vowels were consistently rated higher in blend than the other vowels studied in the present investigation.

It has been noted earlier that the frequency oscillation of partials is most pronounced for upper partials. In some instances the extent of oscillation is so great that a partial can be exceptionally strong during one phase of the vibrato cycle and completely damped, or missing, during the opposite phase of the vibrato cycle (see Figure 18).

Fig. 18--A sonagram illustrating the increasing vibrato extent of successively higher partials. Note that some partials (indicated by arrows) are, in effect, switched on and off during each vibrato cycle.

This on/off switching effect is most pronounced for partials lying in the general area of 3,000 Hz. At this point the frequency oscillations are great enough to carry them during one phase of the vibrato cycle into the center of the resonance peaks in the spectral envelope and far enough away during the opposite phase of the vibrato cycle for them to be damped completely. Moreover, the resonant

frequency of the ear canal is near 3,000 Hz. Thus, the ear is especially sensitive to frequency components in this range. Of course, at higher frequencies the extent of oscillation of the partials is even greater, but the number and strength of the partials in a vocal sound decrease rapidly, and the ear is progressively less sensitive at higher frequencies.

The on/off switching of strong upper partials has been described as ". . . ringing like a telephone bell" (60, p. 193). It appears that such an effect could adversely affect the perceived vocal blend of a tone with an ensemble. Theoretically, the effect of certain partials switching on and off could be diminished by a reduction in the vibrato extent, a reduction of overall intensity, or a reduction in the relative amplitude of the upper partials. Interestingly, these were the very types of changes employed by the singers for sounds produced in blend context and among the sounds identified as blending well with the ensemble.

The interaction between a vocal tone's frequency oscillations and its spectral characteristics may occur not only at the source of the sound but at the listener as well. How this interaction may occur in the listener's auditory mechanism is conceptually quite similar to the way the interaction occurs in the singer's vocal tract.

Partials at some frequencies are assigned greater subjective loudness than partials at certain other frequencies,

even if the different partials have equal sound pressure levels (5, pp. 231-233).

Benade has prepared a chart showing how the perceived loudness of a sine tone varies according to frequency (5, p. 232). (See Figure 19.)

Fig. 19--The loudness in sones of sine tones in a room as a function of frequency. Each curve is marked with the sound pressure level of the stimulus. For sound stimuli at least 40 db above threshold, a 10 db increase in sound pressure level approximately doubles the subjective loudness (5, p. 232).

In a sense, the resonance curve of the vocal tract and the loudness-response curve of the aural perception mechanism are analogous. In the former, the acoustic input signal (the glottal spectrum) is altered according to the resonance curve of the vocal tract, resulting in reinforcement of some partials and damping of others, depending on their frequencies (see Figure 14, page 115). In the latter, the acoustic input signal (the acoustical spectrum transmitted to the listener's ear from the singer's mouth) is altered according to the response curve of the auditory mechanism, resulting in greater subjective loudness assigned to some partials and less loudness assigned to others, depending on their frequencies.

At the singer, the essence of the interaction between a vocal tone's vibrato and its spectrum of partials is that the resonance curve of the vocal tract is fixed (for a given vowel), while the frequencies of the partials of the acoustical signal input to it are oscillating. In effect, the partials slide higher and lower on the resonance curve of the singer's vocal tract.

At the listener, the essence of the interaction between a vocal tone's vibrato and its spectrum of partials is that the loudness-response curve of the auditory mechanism is fixed, while the frequencies of the partials of the acoustical signal input to it are oscillating. In effect, the

partials slide higher and lower on the loudness-response curve of the auditory mechanism.

The perceived quality of a tone sung with vibrato may thus be influenced by the combined effects of the resonance characteristics of the singer's vocal tract and the loudness-response characteristics of the listener's auditory mechanism.

It has been shown that the perceived loudness of a tone can be affected by the presence of vibrato. In an aural comparison of two complex tones having equal sound pressure levels but differing with respect to the presence of vibrato, the tone with vibrato may be perceived as louder if the frequency oscillations of its partials carry them into parts of the spectrum where the aural perception mechanism is especially sensitive (5, p. 252).

This may be verified, theoretically at least, by considering a complex tone whose fundamental frequency is centered at 250 Hz., whose vibrato varies at an extent 5 Hz. above and below the midpoint of the fundamental frequency, and whose partials have equal sound pressure levels of 80 db. Note that partial four, for example, will have oscillations extending 20 Hz. either side of the midpoint of 1,000 Hz. while partial eight will have oscillations extending 40 Hz. either side of the midpoint of 2,000 Hz. The fluctuations in perceived loudness caused by the vibrato

may be assessed by referring to the 80 db curve in Figure 19, page 169.

It has been shown that, because of the auditory mechanism's loudness-response characteristics, the perceived loudness of a complex tone may be altered significantly by changing the relative distribution of amplitude among its partials without changing the tone's overall intensity (5, pp. 245-246).

It appears that the loudness-response characteristics of the listener may also affect the perceived qualities of a tone sung with vibrato in ways other than loudness. The timbre, sonance, and possibly other aspects of a tone sung with vibrato may be influenced at the listener in ways similar to the manner in which they are influenced at the singer. Conceivably, such changes could affect the vocal blend of a tone in specific ways which are yet unforeseeable.

Additional Observations

It seems a logical expectation that individual vocal sounds intended for projecting over an orchestra to the far extent of an opera house or concert hall would differ acoustically from those intended for achieving vocal blend with an ensemble. The musical objectives are fundamentally opposite. One musical situation demands that the individual voice emphasize its prominence in order to be heard separately. The other musical situation demands that the

individual voice minimize its prominence in order to combine with other voices and create the aural illusion of unity.

The acoustical differences of vocal tones intended for these different musical situations do not, it seems, necessarily imply essential differences in fundamental vocal technique. Rather, they suggest, perhaps, temporary vocal modifications, not altogether different from those required for artful solo performances. The specific acoustical characteristics identified for each kind of vocal sound reveal how each is particularly suited for achieving its own musical objective. Such information may provide insight for teachers, who often must guide singers in achieving various, and sometimes contrasting, musical objectives.

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CHAPTER VI

SUMMARY AND CONCLUSIONS

Introduction and Purpose of the Study

Choral blend often has been a basic objective in ensemble singing, but the diversity of concepts concerning how the phenomenon occurs has led to a profusion of pedagogical techniques (6, pp. 9-13). Approaches calling for singers to modify certain aspects of their solo vocal production for the sake of ensemble blend have sometimes led to controversy among both choral directors and voice teachers (1, pp. 53-56).

While research studies concerning the acoustical qualities of sounds produced in solo singing have made significant contributions to understanding in that area, acoustical studies of choral tone, particularly concerning possible acoustical differences between individual vocal sounds produced in certain solo and ensemble situations, has been almost nonexistent (7, pp. 21-33).

The purpose of this study was to investigate the phenomenon of choral blend through acoustical analysis of individual vocal sounds.

Specific Problems Investigated

The following specific problems were investigated:

1. Identification of the acoustical qualities of individual vocal sounds produced in solo singing.
2. Identification of the acoustical qualities of individual vocal sounds produced by singers attempting to blend with a unison ensemble.
3. Comparison of the acoustical qualities of individual vocal sounds produced in solo singing and corresponding vocal sounds produced by the same singers attempting to blend with a unison ensemble.
4. Identification of the acoustical qualities of individual vocal sounds identified as blending well with a unison ensemble.
5. Identification of the acoustical qualities of individual vocal sounds identified as blending poorly with a unison ensemble.
6. Comparison of the acoustical qualities of individual vocal sounds identified as blending well with a unison ensemble and corresponding vocal sounds identified as blending poorly with a unison ensemble.

Points of Analysis

Acoustical data on individual vocal sounds were gathered for each of the following points of analysis:

1. The overall intensity at the time of recording.

2. The relative intensity of the fundamental frequency and each partial from 85-8,000 Hz.

3. The frequency and relative intensity of the first, second, and third formants.

4. The frequency-variation characteristics of the fundamental frequency; specifically, (a) the vibrato rate, and (b) the vibrato extent.

Limitations

The investigation was limited to studying thirty soprano voices, singing the vowels [α], [O], [U], [ɛ], and [i], each at the pitch levels of C⁴ (261 Hz.), A⁴ (440 Hz.), and F⁵ (698 Hz.). The task in blending was limited to each of the subjects attempting to blend with a prerecorded, unison, soprano ensemble, singing sustained tones with vibrato and using a moderate dynamic level. The individual singers were unrestricted in the vocal modifications permitted. Basic questions concerning the desirability or appropriateness of choral blend or of certain techniques used to achieve it were not addressed by the study.

Methodology

The methodology for the present study was based on techniques developed in a pilot study conducted by the investigator (8). The central aspect of the present study's procedures was that individual voices were

acoustically isolated by special means from the sound of a unison ensemble with which they attempted to blend. This was achieved by having the individuals sing with a prerecorded ensemble heard on earphones while the singer also simultaneously monitored her own voice on earphones.

High quality stereo recordings were made of an ensemble of three heterogeneous soprano voices, singing sustained vowel sounds in unison. The ensemble's blend was of such nature that, upon hearing the recordings played back, the individuals in the ensemble could not discern separately their own voices. Segments of the recordings were made into tape loops. When played for a listener, a tape loop presented a continuously sounding, highly blended, unison ensemble.

Thirty sopranos were selected randomly from a list of sopranos participating in the principal choral ensembles at North Texas State University during the fall semester of 1976. Individually, the subjects sang sustained vowel sounds: (1) produced in the usual solo manner, and (2) produced in attempts to achieve the best possible blend with the ensemble on the tape loops. The same vowels were produced at the same pitch levels in both contexts.

Separate, written instructions were given for producing the sounds in each context. The instructions indicated that when the subject was producing a sound which she regarded as appropriate for the context in which

she was singing, she was to hold that sound approximately three seconds and then stop. Repeated attempts were permitted as needed, but, for a given sound, only the final attempt was used in the study. In each context the tasks were prearranged in random order with regard to the vowel and the pitch level.

As a subject attempted to blend with the ensemble, separate recordings were made simultaneously of the individual's voice: (1) isolated from the ensemble, and (2) combined with the ensemble. From the recordings in the latter case, a blend adjudication tape was prepared. The individual sounds were placed in random order with regard to the subject, the vowel, and the pitch level.

A panel of six selected choral directors listened to the tape and, using a five-point rating scale which they had been trained in using, the judges assigned a rating to each sound on its blend with the ensemble. Each judge listened to the tape at a different time, and to control for the possible effects of learning and fatigue, each judge was started at a different place on the tape. The interjudge reliability, computed in terms of percentage of agreement within ± 1 point, had a median value of 79 per cent.

For a given vowel sung at a given pitch level, the sounds receiving the highest third of the blend ratings were identified as the group of sounds blending well with

the ensemble. Conversely, the sounds receiving the lowest third of the blend ratings were identified as the group of sounds blending poorly with the ensemble.

The recordings of the individual vocal sounds which were isolated from the ensemble sound were used for acoustical analysis. The spectral qualities were assessed by means of sonagrams. The frequency-variation characteristics were assessed by means of graphs made of the sounds' fundamental frequencies. The sounds' overall intensities were measured at the time of recording in decibels with reference to $0.0002 \text{ dynes/cm}^2$. Special displays were prepared for each subject in which the spectral qualities and frequency-variation characteristics for all the tones of a given vowel sung at all three pitch levels in both solo and blend contexts were displayed side by side.

Visual assessments of the sonagrams and graphs of fundamental frequency produced the following information on each sound: the relative intensity of the fundamental frequency and each partial from 85-8,000 Hz., the frequency and relative intensity of the first, second, and third formants, the vibrato rate, and the vibrato extent.

The relative intensity of a given partial was expressed in terms of an intensity rating from 0-5. The vibrato rate was expressed in oscillations per second. The vibrato extent was expressed in cents. The reliability of the data-gathering procedures was checked by assessing a random

sample of sounds a second time. The correlation coefficient between the first and second assessments was 0.8898 in the case of the vibrato rate and 0.9984 in the case of the vibrato extent. In the case of the ratings of each partial on its relative intensity, the percentage of agreement within ± 1 point between the first and second assessments was 99.49 per cent. Random samples assessed by two other observers yielded similar figures of correlation or agreement as those reported above.

Results

The first three specific problems investigated involved identifying and comparing the acoustical qualities of individual vocal sounds produced in solo and blend contexts. In the interest of clarity, the results from the first three investigative problems are reported together.

Overall intensity averaged 74-100 db for the groups of sounds produced in solo context and 69-93 db for the groups of sounds produced in blend context. The level of intensity was higher at each higher pitch level for the sounds produced in both contexts. In each case the groups of sounds produced in solo context had a greater mean intensity level than those produced in blend context. The group-mean differences varied over a general range of 5-9 db. The magnitude of difference increased with the pitch level. All the group-mean differences were statistically significant at the .05 level.

For the vocal sounds produced in both solo and blend contexts, three general frequency-variation types were observed: vibrato, straight tone, and nonperiodic variations. Some sounds changed in type over the duration of the sound, particularly vocal sounds produced in blend context. Greater variety of frequency-variation types was observed among the sounds produced in blend context.

For approximately 90 per cent of the sounds produced in solo context the fundamental frequencies were generally 25-75 cents higher than the fundamental frequency of the pitch pipe on which the notes were sounded. The fundamental frequencies of the sounds produced in blend context often varied 25-50 cents from the target frequency, usually higher. However, the range of the deviations from the target frequency was less for the fundamental frequencies of sounds produced in blend context.

Vibrato rates averaged 5.13-5.57 oscillations per second for the groups of sounds produced in solo context and 4.60-5.28 oscillations per second for the groups of sounds produced in blend context. The vibrato rate often was greater among the sounds produced in solo context. The group-mean differences were slight, although usually statistically significant at the .05 level.

The vibrato extent averaged 59-83 cents for the groups of sounds produced in solo context and 58-69 cents for the groups of sounds produced in blend context. The sounds

produced in solo context had a greater vibrato extent than the sounds produced in blend context, the differences between the group means ranging 2-12 cents. The group-mean differences were generally not statistically significant at the .05 level.

The fundamental frequency was strong for sounds produced in both solo and blend contexts, sometimes stronger for sounds produced in blend context. Partial above the first formant were less in relative amplitude for sounds produced in blend context than for sounds produced in solo context. Energy on the partials above 5,000-6,000 Hz. was practically inconsequential for sounds produced in both contexts, except for a few sounds on the vowels [ɑ] and [ɛ].

Vowel formant frequencies were approximately the same for a given vowel sung in both contexts, except for a few sounds produced in blend context, where there were occasionally slight downward shifts of the second formant of [i] and the third formants of all the vowels. Typically, the first formant was approximately the same relative amplitude for sounds produced in both contexts, sometimes slightly stronger for sounds produced in blend context. The second formant was substantially less in relative amplitude for sounds produced in blend rather than solo context. The third formant was much less in relative amplitude, but

not eliminated altogether, for sounds produced in blend rather than solo context.

The last three specific problems investigated in this study involved identifying and comparing the acoustical qualities of individual vocal sounds identified as blending well and blending poorly with a unison ensemble. In the interest of clarity, the results from the last three investigative problems are reported together.

Overall intensity averaged 67-93 db for the groups of sounds identified as blending well with the ensemble and 71-95 db for the groups of sounds identified as blending poorly with the ensemble. The group-mean differences varied over a general range of 1-5 db, the groups of sounds identified as blending well having the smaller value. The magnitude of difference was slightly greater at the lowest pitch level. The group-mean differences were usually not statistically significant at the .05 level.

Straight tones, nonperiodic variations, and modifications of vibrato were observed more often among vocal sounds identified as blending well with the ensemble than among those identified as blending poorly with the ensemble. For a given vowel and pitch level, the fundamental frequencies of most of the sounds identified as blending poorly with the ensemble lay well within the frequency band encompassed by the fundamental frequencies of the sounds identified as blending well with the ensemble.

In order to receive high ratings of blend, sounds with weak and/or few upper partials appeared to be permitted greater discrepancies of alignment of their fundamental frequencies with the target frequency than sounds with strong and/or numerous upper partials.

Vibrato rates averaged 4.50-5.32 oscillations per second for the groups of sounds identified as blending well with the ensemble and 4.77-5.27 oscillations per second for the groups of sounds identified as blending poorly with the ensemble. The mean vibrato rate was sometimes greater for the groups of sounds identified as blending poorly and sometimes greater for the groups of sounds identified as blending well. None of the group-mean differences was statistically significant at the .05 level.

The vibrato extent averaged 36-66 cents for the groups of sounds identified as blending well with the ensemble and 59-78 cents for the groups of sounds identified as blending poorly with the ensemble. The mean vibrato extent was less for the groups of sounds identified as blending well with the ensemble than for the groups of sounds identified as blending poorly with the ensemble. The group-mean differences varied over a general range of 1-30 cents. They were generally not statistically significant.

At the lowest pitch level, the fundamental frequencies were often stronger for sounds identified as blending well with the ensemble than for sounds identified as blending

poorly with the ensemble. At the middle and upper pitch levels, the fundamental frequencies appeared to be roughly equal in relative intensity for both groups. At the middle and upper pitch levels, the fundamental frequency appeared to be the strongest element in the spectral profile for the sounds of both groups.

Partial above the first formant were less in relative amplitude for the groups of sounds identified as blending well with the ensemble than for the groups of sounds identified as blending poorly with the ensemble. Above 5,000 Hz. there was little significant energy present in the sounds of either group.

Vowel formant frequencies were approximately the same for a given vowel at a given pitch level in both groups, except for a few sounds identified as blending well with the ensemble, where the second formants of [i] and the third formants of all the vowels occasionally were slightly lower in frequency than for sounds identified as blending poorly with the ensemble. The first formant was sometimes slightly stronger among the groups of sounds identified as blending well. The second and third formants had less relative amplitude among the groups of sounds identified as blending well than among the groups of sounds identified as blending poorly with the ensemble.

Conclusions

The limitations of the investigative situation apparently restrict the extent to which certain specific results of the study (e.g., the particular vibrato rates of vocal sounds produced in attempts to blend with the ensemble) may be broadly generalized. However, there were a number of overall patterns observed which were consistent throughout the study and which were found to be in general agreement with evidence from related studies. Such patterns may represent aspects which may be more broadly generalized than certain of the specific results on which they were based. These patterns suggest a number of conclusions concerning certain areas of the first three specific problems investigated in the study.

Acoustical Differences of Vocal Sounds Produced in Solo and Blend Contexts

Singers attempting to achieve vocal blend reduce their overall intensity from levels ordinarily employed in solo singing. In contrast with vocal sounds produced in solo singing, vocal sounds produced in attempts to blend tend to exhibit more different frequency-variation types (vibrato, straight tones, and nonperiodic variations), and the fundamental frequencies of such tones tend to be closer to the target frequency.

In attempting to achieve vocal blend, a singer may or may not alter the frequency and/or frequency-variation

characteristics of the vocal tone from patterns ordinarily employed in solo singing. The degree to which such alterations are made appears to depend on a complex set of circumstances, including the overall acoustical characteristics of the individual sound and the ensemble sound and the individual singer's personal approach to achieving a blend.

Vocal sounds produced in choral blend situations may have approximately the same formant frequencies for the first three formants as vocal sounds produced on the same vowel and pitch level in solo singing situations. However, in contrast to vocal sounds produced in solo singing, those produced where efforts are made to achieve maximum vocal blend with an ensemble tend to have slightly stronger first formants in combination with weaker second and third formants.

Vocal sounds produced in choral blend situations also differ in regard to certain other spectral features from corresponding sounds produced in solo singing: the fundamental frequency may be slightly stronger at low pitch levels; the partials above the first formant are fewer and generally have less relative amplitude; and partials lying on frequencies between the formant frequencies tend to have less relative amplitude.

Acoustical Differences of Vocal Sounds
Identified as Blending Well
and Blending Poorly

Several patterns observed in the present study suggest a number of conclusions concerning certain areas of the last three specific problems investigated in the study.

Vocal sounds which blend well with a unison ensemble tend to have a slightly lower level of overall intensity in some cases than vocal sounds which blend poorly with a unison ensemble. In contrast with vocal sounds which blend poorly with a unison ensemble, those which blend well tend to employ more different frequency-variation types (vibrato, straight tones, and nonperiodic variations), and their fundamental frequencies tend to be closer to the target frequency. Vocal sounds which blend well with a unison ensemble tend to employ a smaller vibrato extent and approximately the same, or a slightly slower, vibrato rate than vocal sounds which blend poorly with a unison ensemble.

The fundamental frequencies of vocal sounds which blend well with a unison ensemble do not necessarily have a closer alignment with the target frequency than the fundamental frequencies of vocal sounds which blend poorly with a unison ensemble. The degree to which misalignment of the fundamental frequencies is permissible before the vocal blend is affected adversely appears to be moderated by a given tone's spectral characteristics. Specifically,

it appears that the fewer and/or weaker the upper partials of a tone, the greater the permitted discrepancies of alignment with the target frequency before the vocal blend is adversely affected.

For the same vowel sung at the same pitch level, vocal sounds which blend well with a unison ensemble tend to have approximately the same formant frequencies as vocal sounds which blend poorly with a unison ensemble. However, in contrast to vocal sounds which blend poorly with a unison ensemble, those which blend well tend to have a slightly stronger first formant in combination with weaker second and third formants.

Vocal sounds which blend well with a unison ensemble also differ in regard to certain other spectral features from vocal sounds which blend poorly with a unison ensemble: the fundamental frequencies may be slightly stronger at low pitch levels; the partials above the first formant generally are fewer and have less relative amplitude; and partials lying on frequencies between the formant frequencies tend to have less relative amplitude.

Choral Blend and the Acoustical Qualities of Vocal Tones

Several patterns observed in the present study suggest a number of general conclusions regarding certain relationships between choral blend and the acoustical qualities of vocal tones sung by soprano voices.

In certain cases, reducing the overall intensity of sung tones has been shown to result in complementary changes relating to vowel quality, vocal registration, and, with regard to vocal blend, the intensity vibrato. Reducing the overall intensity also has been shown to result in a reduction in the number of upper partials present in soprano tones. (See Chapter V, pages 111-123.) In the present study, when singers modified their vocal production in efforts to achieve vocal blend, acoustical changes such as those described above paralleled reductions of overall intensity from levels typically employed for corresponding tones in solo singing.

In view of this evidence, it seems reasonable to conclude that singers attempting to achieve vocal blend adjust their overall intensity not only to affect the perceived loudness of their tones, but also to facilitate other acoustical changes in their vocal sounds, which are perceived as helpful for achieving vocal blend. Specifically, in the interest of achieving vocal blend, singers may reduce their levels of overall intensity as means to correct or to alter any of the following aspects: conspicuous loudness, the glottal spectrum, certain detrimental vocal qualities associated with oversinging and improper vocal registration, a prominent intensity vibrato, and the masking of the ensemble sound heard by the blending singer due to his own loud sound.

In view of the spectral characteristics observed in the present study for vocal sounds which were identified as blending well with the ensemble, there appears to be a relationship between the number and relative amplitude of upper partials present in an individual vocal tone and the readiness with which such a sound may blend. The findings of the present study accord with those of a study by Hunt (9, p. 96) in pointing to the conclusion that vocal blend apparently may be achieved more readily on vowels having few upper partials, such as [U] and [O], rather than on vowels having numerous upper partials, such as [E].

The importance of accurately aligned vocal pitches has been widely recognized as a crucial factor influencing vocal blend (6, pp. 9-13). However, from the results of this study it is evident that where a moderate amount of vibrato is employed within an ensemble sound, certain vocal sounds can achieve a good blend with that ensemble even when their fundamental frequencies only approximate the theoretically correct frequency of the target pitch.

The fundamental frequency of a given vocal sound was examined in the present study, not its pitch, which is a subjective sensation requiring specialized procedures to evaluate. There is no conclusive evidence to indicate how the perceived pitch of a vocal tone, especially one sung by a soprano voice and employing vibrato, is related to the tone's fundamental frequency. Therefore, it is not possible

for this investigation to provide a definitive answer concerning the question of how crucial a factor accurately aligned vocal pitches are in the matter of choral blend. (See Chapter V, pages 130-146.) However, it appears that the subjective pitch of a vocal tone may be influenced by the combined factors of the vowel sung, the number and relative amplitude of the upper partials, the various parameters of vibrato, and the overall intensity.

The findings of this study support the conclusions of other studies (12, p. 159; 10, pp. 181-184; 16, p. 128), which indicate that the deviations of performers from the theoretically correct notes are so great as to exceed vastly the boundaries of any tuning system, e.g., Pythagorean, just temperament, and equal temperament.

The overall results of this study suggest the concept that a tone's vocal blend is related to the combined effects of certain acoustical qualities rather than being a simple function of a single acoustical element. This concept is supported by the finding of the present study that different vocal sounds may be judged as blending well with a given ensemble, even though those individual vocal sounds may possess somewhat different acoustical characteristics.

Differences among singers in the nature of their vocal modifications in blending appear to be attributable in part to their choices among their available options, which, in various combinations, may be advantageous for achieving

blend, e.g., whether to reduce the relative amplitude of the upper partials, to use a straight tone, or to employ a smaller vibrato extent. As a practical matter, it appears that different options offer their own advantages and disadvantages in terms of the magnitude of their effects upon the ensemble blend, the readiness with which particular vocal changes may be achieved physically by different singers, and the extent to which certain vocal techniques accord with certain personal preferences in regard to style and taste.

A conclusion related to the ideas mentioned above is that there apparently is no fixed hierarchy of importance among the acoustical factors influencing vocal blend, whereby one or two factors, such as vowel quality or vibrato characteristics, assume preeminence for every singer in a given choral blend situation. Rather, it appears that in a given choral blend situation the relative importance of a particular acoustical characteristic in affecting the blend of an individual vocal sound with an ensemble may vary with different individuals and different ensembles, depending on the total set of acoustical features presented by each sound source.

Evidence concerning the resonance characteristics of the singer's vocal tract and certain traits of the listener's auditory mechanism support the concept that the combined effects of a vocal tone's vibrato and its spectral

features may influence certain perceived qualities of the vowel, the timbre, the sonance and the loudness of a given tone, thereby affecting the readiness with which that tone may blend with a given ensemble. This interaction between the vibrato of a vocal tone and its spectral features apparently makes it advantageous for the individual singer to adopt mutually beneficial approaches to both factors in order to achieve vocal blend with an ensemble. (See Chapter V, pages 164-172.)

Evidence provided by several studies concerning the spectral characteristics associated with various types of vowel quality and vocal timbre in singing accord with evidence from the present study concerning the spectral differences observed between vocal sounds identified as blending well and blending poorly with the ensemble and between vocal sounds produced in solo and blend contexts. (See Chapter V, pages 146-164.) This evidence suggests that vowel modification which is effective for achieving vocal blend consists of altering the shape of the spectral profile so that the first formant is the most prominent feature and so that there is minimal acoustical energy in the frequency regions between the formant frequencies.

Cautions Concerning Generalizing the Findings

The conclusions of this study are, of course, based on observations of one particularly well-defined situation:

individual soprano voices attempting to achieve unison blend with a small soprano ensemble of heterogeneous voice-types, singing in unison at a moderate dynamic level and employing a moderate degree of vibrato. Moreover, the individual singers attempting to blend with the ensemble were unrestricted in the vocal modifications permitted. The extent to which the findings may be more broadly generalized is presently undetermined.

If any of the acoustical parameters of the investigative situation were to be changed significantly, it is expected that those changes would also be reflected in the particular acoustical characteristics exhibited by the individual singers attempting to blend in such a situation. However, it is expected that the various acoustical and perceptual factors identified in the present study as governing or moderating the processes of achieving vocal blend would essentially remain, e.g., the combined effects of a tone's spectral features with its vibrato characteristics and/or its overall intensity.

The fact that the same kinds of results were obtained consistently for a randomly selected group of thirty subjects across five vowels and three pitch levels reinforces the above expectation. Additional support is indicated by the fact that similar results were obtained in the pilot study (8), in which a different ensemble and a different set of subjects were employed.

The main contribution of the study may not so much lie in identifying specific acoustical differences between vocal sounds produced in solo and blend contexts or between sounds identified as blending well and blending poorly with a unison ensemble, as in pointing out certain acoustical and perceptual factors which may participate in governing the phenomenon of choral blend. Such factors may fundamentally be the same, regardless of the specific choral blend situation.

A Theoretical Model of the Blend Process

A theory, embodying a synthesis of certain acoustical and perceptual processes possibly influencing choral blend, grew from the present investigation. Although not an integral part of the study, in the sense of being one of its stated objectives, the theory involves concepts which may be of interest for further investigations.

Even as the present investigation began, it was evident that the individual's task in achieving vocal blend with an ensemble involved a coordination of the mechanisms of vocal production and aural perception. A singer compared her vocal output aurally with the sound of the ensemble and then employed successive vocal modifications until minimal elements of her sound were detected protruding from the sound as a whole.

As the study progressed and the blending process was considered from various perspectives, it further appeared

that there were common intermediate tasks, or steps, in the blending process and that success in blending depended on the actions taken by a singer at each junction. Furthermore, the differences among different individuals in their approaches to blending appeared to arise from their different ways of handling these common intermediate tasks.

For example, some subjects reported being unable to pinpoint the specific elements of their own sounds which disrupted their blend with the ensemble. This prevented them from making intentional vocal changes effective for achieving a blend, except on a trial-and-error basis.

Other subjects, who by their own report were able to identify those elements of their sounds disturbing their blend with the ensemble, said that they were somehow unable to alter their own sounds in a manner effective for achieving a good blend with the ensemble.

Some individuals seemed to have no clear conception of what constituted an optimum vocal blend. Even though they demonstrated the ability to discriminate certain details in the sound, as well as the ability to control their own sounds as desired, such individuals seemed not to recognize when their vocal modifications brought them into closest unity with the ensemble.

After considerable reflection upon these observations in light of the results from the study as a whole, there was hypothesized a sequence of actions employed by a singer

attempting to blend. It was found that this sequence of actions, derived in part from certain contemporary theories concerning the ways in which aural information is processed by the brain, closely resembled cybernetic models of the speech process. These models propose that the coordinated systems of speech function as a servomechanism, i.e., a device operating under automatic control.

Further examination indicated that the hypothesis seemed to explain many of the suggested techniques for achieving vocal blend commonly found in the pedagogical literature. The theory further appeared to have potential for making theoretical and practical contributions to the field of choral teaching, particularly in the area of rehearsal techniques concerned with choral tone.

The basic features of this hypothesis are now presented in conjunction with their parallel features from cybernetic models of the speech process, concepts of which have been developed over some twenty years and have found practical application in speech therapy.

The term cybernetics (from the Greek *kubernētēs* = steersman) was adapted by Norbert Wiener in 1948 in connection with his study of communication and control in the theory of messages (15). A servomechanism, as the concept prevails in the field of engineering, is a device that automatically operates and controls various kinds of machines (11, p. 5). These devices are goal-directed,

error detecting, error measuring, automatically self-adjusting mechanisms that control a machine by feeding information back into it concerning the machine's performance, thereby effecting appropriate corrections whenever performance errors are detected (11, pp. 6-7). Familiar mechanisms of this type include home heating and cooling units, refrigerator thermostats, and missile guidance systems.

Fulton (5) has indicated that many activities of the human organism involve servomechanism functions, e.g., the processes responsible for physiological homeostasis, such as the constancy of temperature, water, sugar, calcium, oxygen, blood circulation, and food intake (11, p. 7).

Fairbanks (3) has incorporated servomechanism functions into an operational theory of the speech mechanism. Mysak (11) has applied the concept of servomechanisms to a theory of speech therapy. The principle has been extended in practical applications to articulation therapy in both the clinic (13) and the classroom (14).

The essence of the servomechanism concept of speech production is that the feedback of sensory information enables a person to control and adjust his speech.

As he talks, he hears himself (audition), he feels his tongue against his palate, his lip touching his teeth, etc. (tactition), and he senses the location and amount of muscle tension or joint movement (kinesthesia) his body is undergoing (4, p. 27).

Feedback is seen to involve three factors: inspection, comparison, and correction. Inspection involves listening to the sounds produced (audition), noting the points where the articulators touch (tactition), and being aware of the amount of tension involved in the articulation (kinesthesia) (4, p. 27).

Comparison involves making point-to-point comparisons of each aspect of the actual speech output with the sound stored in the auditory memory in order to discover the nature and extent of error (4, p. 29).

Correction involves relaying corrective data to the motor area of the brain, which is the origin of the nerve impulses to the muscles controlling the speech output. Precorrection is a phase of the correction stage in which the speaker conceives, or "prehears," the word he is about to speak, inspects the set of muscles about to be employed in producing the word, and makes required corrections in muscular control as the word is spoken (4, p. 29). As Fisher has noted, ". . . this entire process operates with phenomenal speed" (4, p. 29).

The process occurs in the form of a loop. Part of the output (the sound) is fed back into the organism, where it is compared with the goal (the intended sound). A resulting error signal is then sent to the motor control center of the brain, which sends nerve impulses to effect appropriate changes in the muscles controlling the sound output.

When the process is first being learned, by a child, for example, each stage has to be consciously controlled. But as a goal is reached successfully (the articulators so controlled that the utterance is correct) and reinforced (by approval actions of a parent), the process becomes automatic (4, p. 30).

It is believed that, for a given vocal utterance, the brain stores the aural sensations associated with the acoustical features of the sound along with the tactile and kinesthetic sensations associated with vocal production of the sound. Thus, a given sound is identified with specific aural, tactile, and kinesthetic sensations associated with the sound and stored in the speaker's memory (13, p. 111).

By implication, failure to utter a sound correctly is chargeable to one or more facets of the process. Wrong information may be stored in the memory. In the case of aural sensations, this could result from defective hearing, for example. In the case of tactile and kinesthetic sensations, it could result from reinforcement of incorrect articulatory positions (approving the utterance "tandy" rather than "candy," for example).

Even with correct information stored in the memory, the process may be disrupted if the feedback links function poorly. For example, a shot of novocaine at the dentist's office may result in temporary interruption of the normal tactile and kinesthetic sensations of speech, even though

the aural feedback is often sufficient to maintain intelligibility. Similarly, an individual listening to music on earphones and trying to carry on a conversation simultaneously may make his voice louder than normal in order to offset his reduced ability to hear himself.

Articulation therapy, based on the servomechanism concept, involves identifying the stage or stages in the speech process where a given articulation problem originates and utilizing therapeutic techniques to reopen the feedback loop to conscious control. This permits the client to recognize the cause of the articulation problem and to concentrate on learning a new mode of approach, which, through practice and guidance from the therapist, then becomes, hopefully, a natural and automatic part of the client's speech habits (4, pp. 30-33; 13, pp. 119-163).

A cybernetic model of the individual singer's task in achieving a blend with an ensemble is represented schematically in Figure 20, page 209. This schematic representation was adapted from similar diagrams by Fisher (4, p. 28) and by Denes and Pinson (2, p. 5), illustrating analogous tasks in speech. The processes described in each of the five steps to follow are based on similar processes suggested by Fisher (4, pp. 25-33), Van Riper and Irwin (13, pp. 105-111), Mysak (11, pp. 17-33), and West (14, pp. 51-60) for operation of the speech mechanism. Technically, each of the stages might be further broken down into smaller steps.

5. Compares sensations with reference.

Fig. 20--Schematic representation of cybernetic model of individual singer's task in achieving vocal blend with an ensemble.

However, for purposes of clarity and simplicity, the stages described seem sufficient.

First, the singer conceives the sound about to be produced. He has a mental image of the aural sensations associated with the sound and mental image of the tactile and kinesthetic sensations associated with producing the sound. He literally hears the sound in his mind and imagines the accompanying muscular movements.

Second, the singer produces the sound. By an action of his will, the motor control center of the brain sends nerve impulses which induce action by the muscles controlling breath pressure, phonation, resonance, and articulation.

Third, the singer attempting to blend hears himself and the rest of the singers in the ensemble. The acoustic signals are transformed into neural impulses and sent to the auditory cortex portion of the brain, where they are registered as sensations of sound.

Fourth, the singer perceives details in the sound. The brain scans the sound for recognizable details, identified as pitch, vibrato characteristics, loudness, vowel quality, and timbre. These are compared against a file of such sensations stored in the auditory association area of the brain. The singer's ability to discriminate acoustical details is dependent on his having stored in his memory a corresponding aural reference with an attached meaning. For example, the aural sensation associated with the concept of

flatness or sharpness has as a stored reference similar sensations of tones being misaligned with respect to one another. These stored sensations represent sensory experiences which the singer at some time in the past learned to associate with the appropriate concept.

Fifth, the singer evaluates the blend of his own voice with the ensemble. The incoming aural sensations are compared point-by-point with a reference--a set of aural sensations stored in the auditory memory and associated with the concept of vocal blend. The extent of detail for which comparisons are possible is dependent on the extent to which certain aural details are stored with an attached meaning in the singer's auditory memory, as described in the preceding step. If differences are noted, an altered sound is conceived. The aural, tactile, and kinesthetic sensations associated with the new sound are preinspected as the motor control area of the brain sends appropriate neural impulses to effect the required muscular movements of the vocal mechanism.

This process results in a loop, producing continuous acoustical alterations of the sound output until stability is maintained, i.e., either the intended goal is reached or another, perhaps arbitrary, goal is substituted.

The actions are those of a servomechanism: a goal-seeking, error detecting, error measuring, automatically self-adjusting unit. Failure to achieve the goal (vocal

blend) is thus chargeable to one or more of the stages in the process. As in the analogous situation of speech therapy, a given singer's difficulty in blending may be identified by assessing the singer's success at each step. Remedial or training activities are then suggested by implication. In this manner, development of a vocal blend may proceed in a logical manner by using techniques aimed at achieving specific, identifiable goals. Logically, any other choral objective similarly related to vocal blend--choral tone and balance, for example--may be approached in a similar way.

On the surface it may seem like this is taking a rather routine musical task and making it needlessly complex. In fact, it is a complex task, and that it can be accomplished with such apparent ease by some individuals is a tribute to the marvelous capabilities of the human brain and nervous system.

"But," it might be asked, "Would not directing attention to such minute details of the process be confusing, if not impossible, for singers just trying to blend?"

Perhaps this would be so, assuming that the theoretical concepts could even be learned by the ordinary choral singer without a whole course of instruction devoted to them. The point, however, is that an understanding of the basic features in the process could conceivably make it possible for choral directors to structure their rehearsal procedures,

singer placement, and related tasks so that the principles were taken into account by the choral singers without their having necessarily to be conscious of them.

Exercises, drills, and similar activities could be designed to incorporate practice of the vocal and perceptual skills pointed out by the cybernetic model. The more highly motivated choral singers might desire to understand the rationale for the use of certain procedures. This would provide an opportunity to explain some of the broader aspects of the cybernetic model to them.

Past pedagogical approaches for achieving vocal blend have basically consisted of suggesting specific techniques which the pedagog had found to work, e.g., rounding the lips for certain vowels, matching vowels, or rearranging the physical positioning of the singers. Essentially, this amounted to sharing one's "bag of tricks." While this process may have served well, it has suffered for lack of understanding concerning how vocal blend resulted when the techniques were employed. As a result, choral directors typically have resorted to collecting all the techniques they could find, experimenting with variations of their own, and trying what seemed to work.

However, when certain techniques are reviewed in conjunction with the suggested cybernetic model and with certain findings of the present study, the effectiveness of certain techniques in many cases seems logically

explained. Moreover, it appears possible for choral directors to use the cybernetic model as a theoretical springboard for new ideas. The generalized concepts of the model may thereby serve as guiding principles through a chain of logic to specific procedures for day-to-day use in choral rehearsals.

The model of the blend process may be helpful as a tool in choral pedagogy. Each event in the sequence suggested by the model could serve as a subject for class discussion, an aspect to evaluate in observations of choral teaching, or an area to investigate in student projects. Additional implications of the cybernetic model may result as the concepts are explored further.

Recommendations for Further Research

The cybernetic model of the individual singer's task in blending with an ensemble suggests a number of specific areas for further research. Areas involving the perception of vocal pitch, vibrato, and timbre could help fill out the skeletal nature of the paradigm. Investigations concerning the influence of such factors as room acoustics, singer-to-singer proximity, and overall group intensity on the individual singer's aural feedback are further possibilities.

Studies similar to the present study should be made with other voice-types, e.g., altos, tenors, and basses, in order to determine the extent to which the findings might

correspond to the present findings for soprano voices. Further acoustical studies might address the matter of choral blend in those situations where there is little or no attempt by singers to modify their vocal sounds in order to achieve a blend. Such a study would concern itself with the acoustical qualities of vocal sounds which appear to blend "naturally."

Additional acoustical studies of choral blend could investigate the matter of "vertical" blend, i.e., the blend of vocal sounds on certain intervals or chords. Such a study might explore the possible interrelationship of vowel formant frequencies with the combined partials of simultaneously sounding tones on different pitches. Similarly, acoustical explanations might be sought for why certain combinations of intervals, chords, and vowel sounds appear to be especially sonorous. The influence on choral blend of attacks, i.e., the buildup of partials at the beginnings of sounds, is another topic for investigation.

The development and validating of pedagogical methods and materials for achieving choral tone, blend, and balance, based on acoustical and psychoacoustical principles, is a current need and a possible area of investigation.

Consideration of choral blend from the standpoint of the listener is a possible area for further research. The influence on choral blend of singer positioning, listener

positioning, room acoustics, and related factors could be aspects to consider in such an investigation.

Further research is needed concerning the relationship between a vocal tone's perceived pitch and its fundamental frequency, its spectral features, and its vibrato characteristics.

The whole area of the acoustics of choral sound furnishes a fertile field for further research. In the past, dissertations and faculty research projects in choral music typically have dealt with choral literature, the development of pedagogical materials, or surveys and opinionnaires (7, pp. 21-23). Meanwhile, acoustical studies of the solo voice have made significant contributions to the field of solo singing in the past two decades.

Vocal pedagogy texts and journals of interest to voice teachers have shown increasing amounts of print devoted to acoustical principles. More importantly, perhaps, pedagogical techniques described in such sources have reflected an increased understanding of how the contributing acoustical factors may be considered in private voice teaching.

In a similar way, further investigations of the acoustical nature of choral singing may lead to an increased understanding of how acoustical concepts may be applied to choral teaching.

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APPENDICES

APPENDIX A

TECHNICAL SPECIFICATIONS OF THE RECORDING EQUIPMENT

TABLE XIII
RECORDER SPECIFICATIONS

Model	Wow and Flutter Percent	Signal to Noise Ratio	Frequency Response
Teac A-3300S-2T	0.06%	60 db.	25-28,000 Hz.
Teac A-1230	0.10%	55 db.	30-20,000 Hz.
Sony TC-280	0.10%	55 db.	40-21,000 Hz.

Amplifier Specifications (Acoustic
Research Model R)

Power output, each channel, with both channels driven:
60 watts RMS, 4 ohms; 50 watts RMS, 8 ohms; 30 watts RMS, 16 ohms.

Distortion at any power output level up to and including full rated power: IM (60 & 7,000 Hz., 4:1), less than 0.25%; harmonic distortion, less than 0.5% from 20 Hz. to 20,000 Hz.

Frequency response: 1 db, 20 Hz. to 20,000 Hz. at indicated flat tone control settings, at full power or below.

Signal to noise ratio: tape playback and special inputs, 75 db, "C" weighting.

Microphone Specifications (Realistic 33-1045-A)

Cardioid response pattern; 30-15,000 Hz. (± 3 db)
frequency response; -72 db (± 3 db) sensitivity; 600 ohms
impedance; electrolet condenser type.

Fig. 21--Frequency response curve for TDH-39 ear-
phone.

APPENDIX B

INSTRUCTIONS TO SUBJECTS FOR SOUNDS
SUNG IN SOLO CONTEXT

Instructions* (Solo)

1. The vowel you are to sing is indicated on the card held up by the researcher in the control room.
2. Sing that vowel on the pitch given by the pitch pipe over the intercom.
3. Sing in the manner you normally would for a solo.
4. When you are producing a sound which you regard as typical of your solo singing, hold that sound for about three seconds and then stop.
5. If you need to sing a note over again, just say so.
6. Do you have any questions?

*These instructions are written so that they will be the same for everyone.

APPENDIX C

INSTRUCTIONS TO SUBJECTS FOR SOUNDS SUNG IN BLEND CONTEXT

Instructions* (Blend)

1. The vowel you will hear the ensemble singing in unison is indicated on a card held up by the researcher in the control room.
2. Listen to the ensemble and sing with them in unison.
3. Try your very best to blend your voice with the ensemble.
4. Use any singing technique that you believe will improve your blend with the ensemble.
5. Ideally, your voice should blend so well with the group that no one listening to you all together would be able to pick out your voice separately.
6. When you are producing the sound which you regard as your best blend, hold that sound for about three seconds and then stop.
7. If you need to sing a note over again, just say so.
8. Do you have any questions?

*These instructions are written so that they will be the same for everyone.

APPENDIX D

ORIENTATION MATERIALS FOR ADJUDICATORS
OF CHORAL BLEND

Information for Blend Adjudicators

You are an important part of a research project entitled, "An Acoustical Study of Individual Voices in Choral Blend." The part of the study in which you are involved is concerned with discovering the acoustical qualities which distinguish vocal sounds which blend well with a unison ensemble from those which blend poorly with a unison ensemble. A simplified description of the study follows.

A small ensemble of sopranos was recorded in a sound-proof room. They sang five sustained vowel sounds (ah, o, oo, eh, and ee), each in the low, middle, and high vocal registers. These fifteen different sounds were recorded with a blend of such nature that, when the recordings were played back, the singers in the ensemble were unable to single out an individual voice. This blend was achieved without restricting the ensemble to highly homogeneous voices and without having the ensemble sing at a greatly diminished dynamic level or without vibrato. Tape loops were made of the ensemble sounds.

Individual sopranos were selected randomly from a list of singers registered for the principal choral ensembles during the fall semester of 1976 at North Texas State University. These singers individually were then placed in a soundproof room and played the tape loops through earphones. The intensity of the recorded sound presented to their ears

was the same as if they had been present at the time of recording at a distance of two feet in front of the ensemble. The individuals then listened to the ensemble on the tape loops and attempted to blend with them. They monitored their own voices through earphones also.

As a singer attempted to blend with a tape loop, the total sound of her voice, combined with the sound of the ensemble on the tape loop, was recorded. The efforts of thirty singers, individually, to blend with each of the fifteen tape loops were placed in random order on a tape. You are one of six adjudicators selected to rate each of these 450 individual vocal sounds on their blend with the ensemble.

The singers' vocal sounds also were simultaneously recorded independent of the tape loops. Additionally, the singers were recorded singing the same fifteen sounds in their usual solo manner. Another part of the research project is concerned with discovering possible acoustical differences between vocal sounds produced in solo singing and those produced while attempting to blend with a unison ensemble.

The vocal sounds which were isolated acoustically from the ensemble sounds and were recorded were analyzed by various kinds of electronic equipment. Charts and graphs indicating the acoustical qualities of each sound were prepared. It is expected that, eventually, the practical

implications of this research project will be made available to the choral profession.

Instructions for Blend Adjudicators

For each sound that you hear on the adjudication tape you are to listen, judge, and rate the extent to which the individual voice "sticks out" from the ensemble sound. In doing this, you will, in effect, be judging the degree of blend, but in a reverse manner. The rating sheets on which you will record your ratings will be like the example below.

Example of Rating Sheet Format

The extent to which the individual voice sounds different from (separate from or in contrast with) the ensemble sound is:

extremely	large	moderate	slight	none
large				

Do not allow your opinions concerning choral tone, individual voice quality, good or bad vocal technique, performance quality, or whether a given vocal technique is "legitimate" to influence your rating of a given sound on its blend with the ensemble. Remember that you are to rate only the extent to which the individual voice "sticks out," that is, sounds different from (separate from or in contrast with) the ensemble sound. You are not to judge the beauty of the sound or the extent to which you approve the sound.

Before beginning adjudication, you will hear several recorded examples representative of the extreme values at both ends of the rating scale and recorded examples representative of rating values in the middle of the rating

scale. This will give you an idea of the range of sounds you will encounter in judging. You will also hear the sound of the various tape loops alone, without any voice attempting to blend with them. This will give you an idea of what the ensemble sounds like alone. The orientation tape is about ten minutes long.

In all likelihood as you hear the orientation tape, you will find that, generally, the ensemble singing on the tape loops does not sound like "one voice." Rather, you will probably hear what is clearly an ensemble sound, but one in which no individual voice is separately discernible, or "trackable," over any appreciable length of time.

Therefore, in the sounds you will judge, any voice which you can pick out, recognize, and follow aurally is the voice of the individual attempting to blend with the ensemble. Your task is to listen, judge, and rate the extent to which the individual voice "sticks out" from the ensemble sound.

The adjudication tape itself has 450 segments of sound, each about 2-3 seconds in length, and spaced about 7 seconds apart. The numbered order of each sound is announced on the tape immediately before that sound is presented. The running time of the adjudication tape is approximately 75 minutes. You may take rest breaks as desired. You may adjust the sound to any desired level of loudness. You

may hear any sound over again, if you wish. Do you have any questions?

APPENDIX E

SAMPLE PAGE OF ADJUDICATION SHEET

APPENDIX F

ACOUSTICAL CHARACTERISTICS OF EACH VOCAL SOUND PRODUCED IN SOLO CONTEXT

TABLE XIV

ACOUSTICAL CHARACTERISTICS OF SOUNDS SUNG IN SOLO CONTEXT
VOWEL [a] PITCH C⁴ (261 HZ.)

Subject	Recording Order	Intensity (db)	Freq. Type*	Vibrato Rate (cps)	Vibrato Extent (cents)	Relative Intensity of Partial (Rating 0-5)					
						Partial Number					
						1-5	6-10	11-15	16-20	21-25	26-30
1	008	77	V	5.50	84	44444	32222	22221	11000	00000	00000
2	026	69	V	5.25	93	44443	21010	21010	00000	00000	00000
3	039	79	V	4.75	60	44455	32112	32211	11111	00000	00000
4	051	82	V	5.00	56	45554	33333	24443	22222	21122	22222
5	074	80	V	5.63	58	45554	32112	23122	33210	00000	00000
6	077	74	V	5.25	52	44433	11222	22222	10000	00000	00000
7	093	75	V	5.50	70	55555	31222	11333	33311	00000	00000
8	111	76	S			44454	21111	12320	00010	00000	00000
9	121	82	V	5.25	92	44455	42222	23333	33110	00000	00000
10	149	74	S			55454	10000	11010	00000	00000	00000
11	160	81	S			45455	42222	42242	23200	00000	00000
12	180	78	V	5.25	42	45444	20002	22211	10000	00000	00000
13	195	79	V	5.38	87	55454	21121	22111	11000	00000	00000
14	208	79	S			55554	22222	23333	12111	11111	11111
15	224	83	V	5.25	48	45455	54332	23332	22221	11100	00000
16	229	76	N			55432	33332	33333	32222	22221	10111
17	254	80	V	6.00	53	45454	22222	22221	11110	00000	00000
18	267	82	V	5.13	142	55543	22211	33332	10000	00000	00000
19	283	71	V	5.38	55	45544	32211	13323	32220	00000	00000
20	300	73	V	5.25	36	45443	22200	22022	01200	10000	00000
21	307	82	V	5.13	35	44444	32112	24434	44210	00000	00000
22	328	78	S			45444	33332	43333	01110	00000	00000
23	343	79	V	5.25	36	45455	33123	34443	34440	00000	00000
24	350	77	V	5.25	97	45454	33323	44443	31111	10000	00000
25	374	82	V	4.38	50	45544	31222	34444	20000	00000	00000
26	389	72	V	5.50	45	45445	32222	23333	33100	00000	00000
27	395	75	N			55545	31111	12221	10000	00000	00000
28	417	84	V	5.00	117	45555	31223	43334	44332	00000	00000
29	426	75	V	5.50	48	55544	32233	44141	11000	00000	00000
30	445	75	V	5.38	94	44545	32111	01421	12110	00000	00000

*Frequency-variation type: "V" = vibrato, "S" = straight tone, "N" = nonperiodic variation.

TABLE XV

ACOUSTICAL CHARACTERISTICS OF SOUNDS SUNG IN SOLO CONTEXT
VOWEL [a] PITCH A⁴ (440 HZ.)

Subject	Recording Order	Intensity (db)	Freq. Type*	Vibrato Rate (cps)	Vibrato Extent (cents)	Relative Intensity of Partial (Rating 0-5)					
						Partial Number					
						1-5	6-10	11-15	16-20	21-25	26-30
1	010	84	V	5.75	121	55432	33232	00000	000		
2	023	82	V	5.00	24	54421	12121	11000	000		
3	033	89	V	4.88	60	54532	23233	31000	000		
4	050	90	V	5.75	55	55433	35552	22010	211		
5	065	88	V	5.63	34	54321	24431	00000	000		
6	083	80	V	5.25	71	54322	23331	00000	000		
7	094	89	V	5.50	90	45532	22333	31000	000		
8	113	86	V	4.75	48	55521	23322	20000	000		
9	122	89	V	5.00	54	55522	22330	10000	000		
10	140	83	V	5.00	21	54511	22210	00000	000		
11	154	83	V	5.00	43	54442	24431	00000	000		
12	170	81	V	5.88	71	54422	24342	00000	000		
13	181	82	V	5.63	116	55422	12333	00000	000		
14	202	77	V	5.25	56	55432	23333	21000	000		
15	217	92	V	6.00	51	44543	34532	11210	000		
16	230	80	V	6.00	30	55432	23433	31000	000		
17	250	86	V	5.00	37	55422	32321	10000	000		
18	269	88	V	5.00	160	55432	14443	22210	000		
19	277	76	V	5.38	67	55500	02112	00000	000		
20	288	75	V	5.38	69	55432	24242	22200	000		
21	314	87	V	6.00	53	54542	24455	30000	000		
22	329	78	S			54432	24201	00000	000		
23	338	85	V	5.13	57	55431	34442	30000	000		
24	351	86	V	5.88	120	54432	45544	40000	000		
25	371	79	V	4.38	82	55422	24440	00000	000		
26	386	78	V	5.25	28	54532	13333	10000	000		
27	401	82	N			54531	12210	00000	000		
28	416	91	V	5.25	115	55542	34343	32000	000		
29	434	79	V	5.50	64	55422	22412	00000	000		
30	446	88	V	5.25	90	45541	11111	10000	000		

*Frequency-variation type: "V" = vibrato, "S" = straight tone, "N" = nonperiodic variation.

TABLE XVI

ACOUSTICAL CHARACTERISTICS OF SOUNDS SUNG IN SOLO CONTEXT
VOWEL [a] PITCH F⁵ (698 HZ.)

Subject Recording Order	Intensity (db)	Freq. Type*	Vibrato Rate (cps)	Vibrato Extent (cents)	Relative Intensity of Partial (Rating 0-5)					
					Partial Number					
					1-5	6-10	11-15	16-20	21-25	26-30
1009	97	V	6.33	101	55241	00000	0			
2016	98	V	5.42	25	54311	10000	0			
3045	96	V	5.25	72	55333	33000	0			
4047	106	V	5.63	75	54343	20000	0			
5069	107	V	4.63	35	52123	00000	0			
6082	94	V	5.00	86	55222	10000	0			
7098	99	V	5.50	67	55101	10000	0			
8114	94	N			55222	00000	0			
9133	101	S			55333	30000	0			
10143	99	V	3.75	17	55232	20000	0			
11156	105	V	5.50	55	55232	00000	0			
12166	102	V	5.25	29	54132	20000	0			
13185	92	V	5.50	112	55223	32000	0			
14196	104	V	5.50	64	55332	30000	0			
15211	98	V	5.88	72	55445	21100	0			
16235	96	V	4.50	27	55222	20000	0			
17248	105	V	5.00	48	55222	20000	0			
18260	108	V	6.00	149	55222	01100	0			
19274	88	V	5.25	45	55131	10000	0			
20290	92	V	5.63	48	55221	00000	0			
21311	107	V	5.75	36	55343	10000	0			
22325	96	S			55233	00000	0			
23339	104	V	5.13	51	55322	30000	0			
24354	105	V	6.25	87	54345	32000	0			
25365	102	V	4.50	54	55233	00000	0			
26381	99	V	5.38	50	55111	10000	0			
27391	85	S			54100	10000	0			
28419	105	V	4.88	104	55003	21000	0			
29427	95	V	6.13	50	55342	11000	0			
30437	95	V	5.63	57	55222	20000	0			

*Frequency-variation type: "V" = vibrato, "S" = straight tone, "N" = nonperiodic variation.

TABLE XVII

ACOUSTICAL CHARACTERISTICS OF SOUNDS SUNG IN SOLO CONTEXT
VOWEL [O] PITCH C⁴ (261 HZ.)

Subject	Recording Order	Intensity (db)	Freq. Type*	Vibrato Rate (cps)	Vibrato Extent (cents)	Relative Intensity of Partial (Rating 0-5)					
						Partial Number					
						1-5	6-10	11-15	16-20	21-25	26-30
1	003	77	V	5.75	131	45444	31124	10132	11000	00000	00000
2	024	70	V	5.00	87	45441	11111	00000	00000	00000	00000
3	034	76	V	5.00	72	55444	31112	10113	32000	00000	00000
4	058	83	V	5.00	83	45433	11233	43320	00000	00000	00000
5	068	81	V	5.63	49	45442	10000	12122	00000	00000	00000
6	081	76	V	5.25	55	45444	22221	33232	00000	00000	00000
7	096	79	V	5.63	95	45454	30001	01111	11110	00000	00000
8	115	76	N			45454	22332	24242	12310	00000	00000
9	135	73	V	5.50	69	45544	34442	42343	22221	11111	11111
10	145	73	S			45451	00000	00000	00000	00000	00000
11	165	81	V	5.00	39	45441	10000	00001	00000	00000	00000
12	171	85	V	5.38	56	45444	21123	11313	10000	00000	00000
13	186	78	V	5.38	68	45442	11000	21111	00000	00000	00000
14	205	77	V	4.50	41	45430	11000	01011	00000	00000	00000
15	215	83	V	5.50	52	45444	43222	34433	32000	00000	00000
16	234	78	V	6.00	36	55442	32101	22311	10000	00000	00000
17	252	79	V	6.00	41	45441	11100	20020	00000	00000	00000
18	261	83	V	5.00	175	55520	21000	34430	00000	00000	00000
19	285	73	V	5.50	43	45411	10000	00000	00000	00000	00000
20	293	75	V	5.25	45	45431	10000	00000	00000	00000	00000
21	309	82	V	5.50	32	45442	12102	33233	11000	00000	00000
22	317	77	S			45441	01001	10010	00000	00000	00000
23	345	79	V	4.75	45	45454	31122	23332	22331	00000	00000
24	355	78	V	5.25	104	45441	11113	43441	10000	00000	00000
25	367	80	V	6.00	62	45444	11011	41331	00000	00000	00000
26	377	74	V	4.75	39	55443	10101	21122	22000	00000	00000
27	404	78	V	4.00	25	55544	42010	00100	01000	00000	00000
28	412	82	V	5.25	139	45554	31113	30233	33200	00000	00000
29	422	79	V	5.00	41	45441	10001	00000	00000	00000	00000
30	436	72	V	5.13	88	55543	11000	00000	10000	00000	00000

*Frequency-variation type: "V" = vibrato, "S" = straight tone, "N" = nonperiodic variation.

TABLE XVIII

ACOUSTICAL CHARACTERISTICS OF SOUNDS SUNG IN SOLO CONTEXT
VOWEL [O] PITCH A⁴ (440 HZ.)

Subject	Recording Order	Intensity (db)	Freq. Type*	Vibrato Rate (cps)	Vibrato Extent (cents)	Relative Intensity of Partial (Rating 0-5)					
						Partial Number					
						1-5	6-10	11-15	16-20	21-25	26-30
1	006	84	V	5.50	124	55443	33232	00000	000		
2	025	84	V	4.63	43	55402	20001	00000	000		
3	037	84	V	5.50	61	54441	34344	30000	000		
4	060	89	V	5.88	61	54432	34544	10000	000		
5	061	86	V	5.88	53	54420	14420	00000	000		
6	086	81	V	5.25	68	54422	23342	02000	000		
7	105	84	V	5.50	69	55411	12332	31000	000		
8	106	80	N			55300	01100	00000	000		
9	126	85	V	5.50	109	55412	14442	14442	000		
10	146	88	S			54300	20100	00000	000		
11	152	84	N			54300	10000	00000	000		
12	177	85	V	6.00	70	54411	14451	00000	000		
13	184	83	V	5.50	124	55310	00322	20000	000		
14	197	82	V	5.25	74	55421	25441	10000	000		
15	216	84	V	5.88	54	55533	15541	00100	000		
16	238	83	V	6.25	36	55331	12332	00000	000		
17	243	79	V	6.25	37	55422	22311	00000	000		
18	268	92	V	5.13	168	55333	35442	00110	000		
19	271	80	V	5.50	55	55111	01000	00000	000		
20	295	78	V	5.50	68	55411	13131	21000	000		
21	312	87	V	5.50	61	55301	14441	00000	000		
22	318	81	V	4.00	44	44200	00222	00000	000		
23	344	85	V	5.13	49	55432	23332	20000	000		
24	347	87	V	6.00	89	55310	33320	00000	000		
25	372	78	V	4.38	84	54411	14320	00000	000		
26	387	81	V	5.38	29	54410	12122	00000	000		
27	396	85	N			54410	00000	00000	000		
28	408	92	V	5.00	131	55432	34343	30000	000		
29	433	83	V	5.50	80	54110	01000	00000	000		
30	449	79	V	5.25	81	55511	11000	00000	000		

*Frequency-variation type: "V" = vibrato, "S" = straight tone, "N" = nonperiodic variation.

TABLE XIX

ACOUSTICAL CHARACTERISTICS OF SOUNDS SUNG IN SOLO CONTEXT
VOWEL [O] PITCH F⁵ (698 HZ.)

Subject	Recording Order	Intensity (db)	Freq. Type*	Vibrato Rate (cps)	Vibrato Extent (cents)	Relative Intensity of Partial (Rating 0-5)					
						Partial Number					
						1-5	6-10	11-15	16-20	21-25	26-30
1	015	98	V	5.25	84	55341	33000	0			
2	028	98	N			55323	20000	0			
3	044	98	V	5.25	84	55344	43000	0			
4	059	107	V	5.88	67	54242	10000	0			
5	072	103	V	5.50	25	54233	30000	0			
6	089	94	V	4.38	71	55322	20000	0			
7	101	99	V	5.63	74	55101	10000	0			
8	120	100	S			54221	11000	0			
9	124	103	V	4.75	28	55414	21000	0			
10	141	102	V	4.50	16	55002	11000	0			
11	158	104	V	6.00	48	55110	00000	0			
12	175	106	V	4.50	33	54141	30000	0			
13	183	92	V	5.50	90	54222	10000	0			
14	201	104	V	5.75	60	55342	30000	0			
15	218	100	V	6.00	66	55435	32100	0			
16	231	94	V	5.00	29	55233	10000	0			
17	244	97	V	5.50	44	55222	00000	0			
18	262	109	V	5.88	152	55311	11100	0			
19	281	89	V	5.50	44	55330	10000	0			
20	298	93	V	5.50	57	55130	00000	0			
21	313	107	V	5.50	41	55222	10000	0			
22	330	98	V	4.22	19	55211	00000	0			
23	342	106	V	5.25	48	55221	00000	0			
24	346	105	V	6.38	107	54132	22000	0			
25	375	102	V	4.50	69	55222	20000	0			
26	390	96	V	5.75	38	55110	00000	0			
27	403	87	S			54101	00000	0			
28	413	105	V	5.00	100	55232	10000	0			
29	435	94	V	6.25	45	54211	20000	0			
30	442	92	V	5.63	53	55111	10000	0			

*Frequency-variation type: "V" = vibrato, "S" = straight tone, "N" = nonperiodic variation.

TABLE XX

ACOUSTICAL CHARACTERISTICS OF SOUNDS SUNG IN SOLO CONTEXT
VOWEL [u] PITCH C⁴ (261 HZ.)

Subject	Recording Order	Intensity (db)	Freq. Type*	Vibrato Rate (cps)	Vibrato Extent (cents)	Relative Intensity of Partial (Rating 0-5)					
						Partial Number					
						1-5	6-10	11-15	16-20	21-25	26-30
1	005	76	V	5.50	95	45342	21101	10010	00000	00000	00000
2	018	71	V	5.50	89	45341	10010	00000	00000	00000	00000
3	031	73	V	4.63	80	55441	10001	00000	00000	00000	00000
4	054	78	V	5.00	58	55442	21132	23322	10000	00000	00010
5	067	75	V	5.13	44	55411	00000	33331	10000	00000	00000
6	078	72	V	5.00	36	55444	11113	10100	00000	00000	00000
7	099	74	V	5.63	84	55331	10000	10000	00000	00000	00000
8	107	72	N			55420	00000	00000	00000	00000	00000
9	125	73	V	5.25	86	55444	21232	01113	31110	00000	00000
10	144	72	S			55430	00000	00000	00000	00000	00000
11	151	73	S			55432	10010	00000	01000	00000	00000
12	174	77	V	5.00	67	54243	11200	00100	00000	00000	00000
13	191	74	V	5.38	127	55441	00010	00000	00000	00000	00000
14	198	76	V	5.00	53	55422	10002	10132	11000	00000	00000
15	220	78	N			55344	11000	10000	22100	00000	00000
16	233	77	V	5.75	46	55442	20001	10121	00000	00000	00000
17	249	73	V	4.75	49	55442	21011	00100	20000	00000	00000
18	258	77	V	5.25	158	54443	22420	12430	00010	00000	00010
19	275	70	V	5.25	60	55421	10000	11011	00000	00000	00000
20	292	71	V	5.25	52	54231	00010	00000	00000	00000	00000
21	308	75	N			55343	01113	01121	10000	00000	00000
22	321	73	S			55333	10110	00110	00000	00000	00000
23	337	79	V	5.13	46	55441	11101	33101	13100	00000	00000
24	356	73	V	5.50	106	45432	10003	11330	33000	00000	00000
25	363	72	V	4.13	59	55442	10030	00010	00000	00000	00000
26	379	74	N			45232	10012	00010	11000	00000	00000
27	393	75	N			55233	10000	00000	00000	00000	00000
28	418	83	V	4.75	92	45443	11001	00022	02100	00000	00000
29	428	73	V	5.25	65	55411	00000	10000	00000	00000	00000
30	448	68	V	5.00	109	55442	00000	00000	00000	00000	00000

*Frequency-variation type: "V" = vibrato, "S" = straight tone, "N" = nonperiodic variation.

TABLE XXI

ACOUSTICAL CHARACTERISTICS OF SOUNDS SUNG IN SOLO CONTEXT
VOWEL [u] PITCH A⁴ (440 HZ.)

Subject	Recording Order	Intensity (db)	Freq. Type*	Vibrato Rate (cps)	Vibrato Extent (cents)	Relative Intensity of Partial (Rating 0-5)					
						Partial Number					
						1-5	6-10	11-15	16-20	21-25	26-30
1	002	89	V	5.00	127	54300	00000	00000	000		
2	022	84	S			54210	00000	00000	000		
3	035	89	V	5.00	72	54401	00200	00000	000		
4	055	95	V	5.50	73	54422	42420	00000	100		
5	066	96	V	5.50	42	54310	23500	00000	000		
6	084	86	V	5.13	68	53410	11210	00000	000		
7	097	87	V	5.50	67	54300	03100	00000	000		
8	112	83	N			55200	00110	00000	000		
9	132	87	V	5.00	23	55310	00010	00000	000		
10	138	88	S			54100	00000	00000	000		
11	162	86	V	4.75	100	54210	00000	00000	000		
12	176	94	V	6.50	58	53421	20310	00000	000		
13	190	86	V	5.50	134	55200	10000	00000	000		
14	210	84	V	5.25	51	54310	22320	00000	000		
15	212	83	V	5.75	69	54410	12121	00000	000		
16	239	83	V	6.13	44	55221	10101	00000	000		
17	242	82	V	5.75	61	54300	10100	00000	000		
18	259	94	V	5.38	181	55311	15400	00000	000		
19	276	78	V	5.25	48	54210	00000	00000	000		
20	294	83	V	5.25	71	54200	10010	00000	000		
21	306	91	V	5.25	36	54210	02220	00000	000		
22	327	86	V	4.50	18	53000	00000	00000	000		
23	336	93	V	5.25	56	54311	14211	00000	000		
24	359	92	V	5.88	93	54210	44110	00000	000		
25	362	78	V	4.38	90	54100	00000	00000	000		
26	378	84	V	5.25	33	54300	10000	00000	000		
27	397	80	N			53100	00000	00000	000		
28	410	89	V	5.00	143	55411	43343	00000	000		
29	429	82	V	5.38	74	54200	10000	00000	000		
30	438	78	V	5.25	88	54300	00000	00000	000		

*Frequency-variation type: "V" = vibrato, "S" = straight tone, "N" = nonperiodic variation.

TABLE XXII

ACOUSTICAL CHARACTERISTICS OF SOUNDS SUNG IN SOLO CONTEXT
VOWEL [u] PITCH F⁵ (698 HZ.)

Subject	Recording Order	Intensity (db)	Freq. Type*	Vibrato Rate (cps)	Vibrato Extent (cents)	Relative Intensity of Partial (Rating 0-5)					
						Partial Number					
						1-5	6-10	11-15	16-20	21-25	26-30
1	007	98	V	5.50	97	55331	01000	0			
2	017	96	S			55321	00000	0			
3	043	98	V	5.13	56	55331	30000	0			
4	052	109	V	5.88	53	55121	00000	0			
5	071	105	V	5.75	44	54223	30000	0			
6	076	93	V	5.25	83	54321	10000	0			
7	091	89	S			54210	10000	0			
8	117	98	S			54111	00000	0			
9	127	101	N			55331	11000	0			
10	137	100	V	5.00	20	54111	00000	0			
11	159	104	V	5.75	51	55221	00000	0			
12	168	104	V	5.00	30	54232	30000	0			
13	182	92	V	5.38	93	54111	00000	0			
14	199	104	V	6.00	49	55342	21000	0			
15	214	101	V	5.75	62	55445	11000	0			
16	237	95	V	5.50	37	55011	00000	0			
17	253	98	V	6.25	34	55222	00000	0			
18	256	104	V	6.25	196	55221	01000	0			
19	272	87	V	5.25	52	54110	00000	0			
20	289	92	V	5.63	59	55020	00000	0			
21	304	104	V	5.50	34	55222	00000	0			
22	319	95	V	4.88	35	55100	00000	0			
23	332	107	V	5.50	47	55111	10000	0			
24	349	105	V	6.25	102	54333	31000	0			
25	370	95	V	4.50	62	55111	10000	0			
26	385	95	V	5.25	34	54120	00000	0			
27	400	88	S			55011	00000	0			
28	415	102	V	5.00	82	55111	00000	0			
29	431	89	V	6.13	44	55110	00000	0			
30	447	91	V	5.63	42	55010	00000	0			

*Frequency-variation type: "V" = vibrato, "S" = straight tone, "N" = nonperiodic variation.

TABLE XXIII

ACOUSTICAL CHARACTERISTICS OF SOUNDS SUNG IN SOLO CONTEXT
VOWEL [ɛ] PITCH C⁴ (261 HZ.)

Subject	Recording Order	Intensity (db)	Freq. Type*	Vibrato Rate (cps)	Vibrato Extent (cents)	Relative Intensity of Partial (Rating 0-5)					
						Partial Number					
						1-5	6-10	11-15	16-20	21-25	26-30
1	014	78	V	5.50	84	45333	34433	31112	21010	00000	00000
2	030	70	V	5.00	59	44422	33312	10001	00000	00000	00000
3	042	76	V	4.88	82	44544	55324	33223	31222	22222	11111
4	057	84	V	4.38	53	45444	55333	33333	21110	00000	00000
5	073	77	V	5.50	61	45444	44433	44334	43111	11111	11111
6	079	75	V	5.25	61	55534	44433	44223	32111	11111	11111
7	100	77	V	5.50	75	45444	45433	34112	33222	22222	22222
8	109	70	S			55443	34532	22222	22222	22222	21111
9	134	75	V	4.88	72	45444	55334	54344	22333	32222	22222
10	143	71	N			45443	22111	10000	00000	00000	00000
11	153	76	S			45444	45324	31121	22200	00000	00000
12	172	88	V	5.00	34	35333	34331	11121	10000	00000	00000
13	189	75	V	5.50	104	55544	55434	41112	21000	00000	00000
14	200	78	V	4.25	58	55444	52223	31123	11111	11111	11111
15	221	85	V	5.50	133	44444	44543	45332	21111	11110	00000
16	232	76	V	6.00	39	55444	53223	43333	11111	11111	11111
17	246	75	V	5.38	52	45443	34333	31122	11001	00000	00000
18	264	84	V	5.25	186	45433	55444	13441	00000	00000	00000
19	284	76	V	5.50	57	45432	33422	11112	20000	00000	00000
20	287	74	V	5.00	44	45422	34223	21112	12200	00000	00000
21	310	80	V	4.50	24	45434	55424	22333	21110	01100	00100
22	316	77	N			45434	44433	31113	10000	00000	00000
23	335	79	V	5.25	76	45444	45334	53333	22211	11110	00000
24	353	77	V	5.38	104	45444	54224	42331	11100	00000	00000
25	364	76	V	4.25	47	45433	44322	42333	10000	00000	00000
26	380	74	V	4.50	37	45423	43233	32222	22210	00000	00000
27	398	74	N			54443	34311	33111	11100	00000	00000
28	411	85	V	5.25	159	45534	55445	41134	44221	10000	00000
29	425	75	V	5.25	42	55444	45334	32231	11000	00000	00000
30	444	74	V	5.25	71	55533	34322	11111	11111	00000	00000

*Frequency-variation type: "V" = vibrato, "S" = straight tone, "N" = nonperiodic variation.

TABLE XXIV

ACOUSTICAL CHARACTERISTICS OF SOUNDS SUNG IN SOLO CONTEXT
VOWEL [ɛ] PITCH A⁴ (440 HZ.)

Subject	Recording Order	Intensity (db)	Freq. Type*	Vibrato Rate (cps)	Vibrato Extent (cents)	Relative Intensity of Partial (Rating 0-5)					
						Partial Number					
						1-5	6-10	11-15	16-20	21-25	26-30
1	013	86	V	5.50	137	54455	33333	10000	000		
2	019	79	V	5.00	36	54432	32022	00000	000		
3	040	90	V	5.00	70	54453	44333	13333	333		
4	053	90	V	5.25	52	54454	44443	11010	100		
5	070	90	V	5.88	48	54453	44540	00020	000		
6	090	79	V	5.25	63	54444	45455	10100	000		
7	095	88	V	5.00	82	45343	23223	21000	000		
8	119	84	N			54433	43233	10000	000		
9	129	84	N			45544	40242	10000	000		
10	148	84	V	4.75	33	54422	41101	00000	000		
11	161	85	V	6.00	49	54454	44440	00000	000		
12	178	83	V	5.75	68	54454	43431	00000	000		
13	194	81	V	5.50	107	55551	33343	00000	000		
14	207	83	V	5.50	60	54541	45451	00000	100		
15	222	85	V	5.88	69	44445	35543	21111	000		
16	236	78	V	6.50	34	55453	35444	21100	100		
17	241	76	V	5.75	67	54354	41243	11000	000		
18	265	88	V	5.25	154	55554	44431	11111	100		
19	278	76	V	5.25	49	53334	41011	00000	000		
20	299	76	V	5.50	58	54343	43242	11000	000		
21	302	85	V	5.50	36	54442	33530	21110	000		
22	322	78	N			54442	33111	00000	000		
23	333	86	V	5.25	65	54453	45232	10000	000		
24	358	86	V	6.25	89	54452	55424	40000	000		
25	366	75	V	4.38	93	54442	44320	00000	000		
26	382	78	V	5.00	29	54423	33331	00000	000		
27	405	80	N			55541	12211	00000	000		
28	406	90	V	5.25	134	55453	43344	20000	000		
29	424	80	V	5.75	70	54254	42411	10000	000		
30	443	81	V	5.50	111	55554	33111	11000	000		

*Frequency-variation type: "V" = vibrato, "S" = straight tone, "N" = nonperiodic variation.

TABLE XXV

ACOUSTICAL CHARACTERISTICS OF SOUNDS SUNG IN SOLO CONTEXT
VOWEL [ɛ] PITCH F5 (698 HZ.)

Subject	Recording Order	Intensity (db)	Freq. Type*	Vibrato Rate (cps)	Vibrato Extent (cents)	Relative Intensity of Partial (Rating 0-5)					
						Partial Number					
						1-5	6-10	11-15	16-20	21-25	26-30
1	012	94	V	5.75	108	55532	22000	0			
2	027	98	N								
3	036	99	V	5.00	73	55453	43100	0			
4	046	104	V	5.63	87	55353	20000	0			
5	063	108	V	5.50	38	54444	21010	0			
6	080	92	V	5.13	82	54441	10000	0			
7	092	93	V	5.75	47	54322	20000	0			
8	116	99	S			54331	20000	0			
9	128	99	S			55442	21000	0			
10	150	99	V	5.25	18	54332	10000	0			
11	157	105	V	5.50	39	54341	00000	0			
12	169	102	V	5.00	29	54441	20000	0			
13	192	94	V	5.50	101	55243	30000	0			
14	203	103	V	5.88	56	54342	11000	0			
15	223	98	V	6.18	80	54555	41100	0			
16	240	97	V	5.63	32	55341	10000	0			
17	247	94	V	5.25	76	54541	20000	0			
18	257	104	V	6.00	211	55221	00000	0			
19	273	87	V	5.25	52	54220	00000	0			
20	286	88	V	5.50	58	54140	00000	0			
21	315	105	V	5.25	32	54443	21000	0			
22	320	95	V	5.00	24	54310	00000	0			
23	341	103	V	5.38	43	54440	22000	0			
24	348	109	V	6.50	81	54441	31000	0			
25	369	96	V	4.50	82	54333	20000	0			
26	383	96	V	5.50	45	54221	10000	0			
27	394	90	N			54311	00000	0			
28	407	105	V	5.00	116	54442	20000	0			
29	432	92	V	6.25	50	55441	00000	0			
30	450	93	V	5.75	46	54311	11000	0			

*Frequency-variation type: "V" = vibrato, "S" = straight tone, "N" = nonperiodic variation.

TABLE XXVI

ACOUSTICAL CHARACTERISTICS OF SOUNDS SUNG IN SOLO CONTEXT
VOWEL [i] PITCH C⁴ (261 HZ.)

Subject	Recording Order	Intensity (db)	Freq. Type*	Vibrato Rate (cps)	Vibrato Extent (cents)	Relative Intensity of Partial (Rating 0-5)					
						Partial Number					
						1-5	6-10	11-15	16-20	21-25	26-30
1	011	72	V	5.50	124	44232	23343	43233	32200	00000	00000
2	020	72	V	4.50	43	45222	22333	10002	00000	00000	00000
3	038	74	V	4.75	59	55112	22333	21111	32210	10000	00000
4	056	80	V	4.88	80	54122	33433	33453	20000	00000	00000
5	064	76	V	5.50	39	54222	33443	45544	45410	00000	00000
6	085	73	V	5.13	60	54312	22443	42242	11000	00000	00000
7	102	77	V	5.13	93	55233	33443	44113	32100	00000	00000
8	108	70	S			55420	00123	23112	21210	00000	00000
9	130	74	V	4.50	72	54422	33344	44555	55442	20000	00000
10	142	73	S			54111	10133	11111	00000	00000	00000
11	163	75	V	5.50	47	55311	33554	31132	11000	00000	00000
12	173	79	V	5.25	55	54111	12424	22342	00000	00000	00000
13	188	73	V	5.25	80	55211	11242	21112	10000	00000	00000
14	206	76	N			54112	23434	43134	21000	00000	00000
15	213	77	V	4.75	34	54122	22245	54444	41000	00000	00000
16	227	75	V	6.38	44	55211	44544	43333	12000	00000	00000
17	255	73	V	6.00	77	55221	11244	32222	10000	00000	00000
18	266	77	V	5.00	176	54312	44543	45554	00000	00000	10000
19	280	71	V	5.25	52	54311	11343	21123	30000	00000	00000
20	291	70	V	5.25	66	54321	31144	30032	11100	00000	00000
21	305	76	S			54111	14443	44444	44011	00001	00000
22	326	77	S			54111	13433	22221	00000	00000	00001
23	331	76	V	5.38	94	55441	22354	44345	43300	00000	00000
24	357	74	V	5.50	109	55312	33454	34444	44100	00000	00000
25	361	72	V	4.25	44	44121	22333	21111	00000	00000	00000
26	376	70	V	4.88	45	55321	22242	22223	13110	00000	00000
27	392	75	S			55111	11113	22110	01000	00000	00000
28	420	80	V	5.25	105	55432	22454	43345	43100	00000	00000
29	430	73	V	5.25	64	55221	22444	11131	11000	00000	00000
30	440	70	V	5.50	81	55311	22224	33212	31000	00000	00000

*Frequency-variation type: "V" = vibrato, "S" = straight tone, "N" = nonperiodic variation.

TABLE XXVII

ACOUSTICAL CHARACTERISTICS OF SOUNDS SUNG IN SOLO CONTEXT
VOWEL [i] PITCH A⁴ (440 HZ.)

Subject	Recording Order	Intensity (db)	Freq. Type*	Vibrato Rate (cps)	Vibrato Extent (cents)	Relative Intensity of Partial (Rating 0-5)					
						Partial Number					
						1-5	6-10	11-15	16-20	21-25	26-30
1	001	88	V	5.50	132	53244	21121	10000	000		
2	029	86	V	5.00	47	53111	11111	10000	000		
3	032	89	V	5.13	69	51344	41143	10000	000		
4	048	94	V	5.25	57	51334	43342	00000	000		
5	062	96	V	5.75	50	52334	24441	00000	000		
6	088	85	V	5.13	64	52222	11110	00000	000		
7	104	85	V	5.50	73	54434	44243	20000	000		
8	118	86	V	4.00	28	54223	33310	00000	000		
9	131	87	N			54334	43442	33000	000		
10	139	92	V	5.00	28	53212	20000	00000	000		
11	164	92	V	6.00	52	51111	00000	00000	000		
12	179	94	V	5.63	60	51335	42342	00000	000		
13	193	87	V	5.50	111	53334	41110	00000	000		
14	209	86	V	5.25	54	53434	33410	00000	000		
15	225	83	V	5.75	86	53334	54454	00000	000		
16	228	82	S			53443	43232	00000	000		
17	251	84	V	6.00	51	53334	41121	00000	000		
18	263	97	V	5.38	171	53344	43400	01100	000		
19	279	80	V	5.25	44	53214	41011	00000	000		
20	297	82	V	5.50	67	52233	41021	00000	000		
21	301	93	V	5.50	42	51331	42110	00000	000		
22	323	87	S			51111	21000	00000	000		
23	340	92	V	5.00	45	54444	44141	00000	000		
24	360	94	V	6.00	95	51445	42422	10000	000		
25	368	81	V	4.25	64	51224	42121	00000	000		
26	384	86	V	5.50	31	51222	21121	00000	000		
27	399	81	N			52100	10000	00000	000		
28	414	90	V	5.50	112	54345	55444	30000	000		
29	423	80	V	5.75	65	54334	31210	10000	000		
30	439	80	V	5.38	103	53212	22002	00000	000		

*Frequency-variation type: "V" = vibrato, "S" = straight tone, "N" = nonperiodic variation.

TABLE XXVIII

ACOUSTICAL CHARACTERISTICS OF SOUNDS SUNG IN SOLO CONTEXT
VOWEL [i] PITCH F⁵ (698 HZ.)

Subject	Recording Order	Intensity (db)	Freq. Type*	Vibrato Rate (cps)	Vibrato Extent (cents)	Relative Intensity of Partial (Rating 0-5)					
						Partial Number					
						1-5	6-10	11-15	16-20	21-25	26-30
1	004	95	V	5.50	99	54552	23000	0			
2	021	93	N			54401	00000	0			
3	041	101	V	5.25	82	54444	42000	0			
4	049	106	V	5.75	63	54532	11000	0			
5	075	98	V	5.63	53	54341	10000	0			
6	087	94	V	5.38	75	54432	10000	0			
7	103	94	V	5.50	85	55422	20000	0			
8	110	93	S			54440	00000	0			
9	123	99	V	4.63	65	54442	20000	0			
10	136	95	V	5.00	24	54430	00000	0			
11	155	104	V	5.00	63	54320	00000	0			
12	167	105	V	5.75	44	53442	31000	0			
13	187	94	V	5.63	89	54442	00000	0			
14	204	103	V	5.75	47	54441	11000	0			
15	219	100	V	5.88	60	54545	32000	0			
16	226	97	V	6.00	50	54430	10000	0			
17	245	94	V	5.13	48	54441	20000	0			
18	270	107	V	5.75	104	54443	00000	0			
19	282	87	V	5.38	44	54110	00000	0			
20	296	90	V	5.50	49	54330	00000	0			
21	303	101	V	5.50	47	54441	11100	0			
22	324	96	N			54310	00000	0			
23	334	107	V	5.50	54	54441	41000	0			
24	352	107	V	6.50	93	54441	20000	0			
25	373	94	V	4.50	74	54543	30000	0			
26	388	95	V	5.38	45	54331	21000	0			
27	402	85	S			54332	00000	0			
28	409	103	V	5.00	102	54442	21000	0			
29	421	85	V	5.75	52	54441	00000	0			
30	441	90	V	5.50	63	54440	00000	0			

*Frequency-variation type: "V" = vibrato, "S" = straight tone, "N" = nonperiodic variation.

APPENDIX G

ACOUSTICAL CHARACTERISTICS AND BLEND RATINGS OF
EACH VOCAL SOUND PRODUCED IN BLEND CONTEXT

TABLE XXIX
ACOUSTICAL CHARACTERISTICS OF SOUNDS SUNG IN BLEND CONTEXT
VOWEL [α] PITCH C⁴ (261 HZ.)

Subject	Recording Order	Intensity (db)	Freq. type*	Vibrato Rate (cps)	Vibrato Extent (cents)	Relative Intensity of Partial (Rating 0-5)						Judging Order	Blend Rating 1-5 By Judge Number	Mean Rating	Group**
						Partial Number									
						1-5	6-10	11-15	16-20	21-25	26-30				
1	453	76	V	4.75	74	44444	32113	21112	22100	00000	00000	014	323222	2.33	L
2	480	69	N			44443	21111	11000	00000	00000	00000	420	323343	3.00	M
3	481	73	V	3.50	29	44455	21222	23111	22101	10000	00000	069	422443	3.17	M
4	508	71	V	4.00	33	55553	22221	23333	22200	00000	00000	218	544443	4.00	H
5	514	74	V	5.25	72	55554	32011	20000	21000	00000	00000	027	112111	1.17	L
6	529	72	S			55435	22222	23333	11111	11111	11111	395	223443	3.00	M
7	544	69	N			55343	11010	01111	00000	00000	00000	220	442444	3.67	H
8	560	74	S			45455	22222	23232	12210	00000	00000	110	211253	2.33	L
9	585	73	S			44354	31111	11233	21100	00000	00000	311	321423	2.50	L
10	597	72	S			44324	01011	01000	00000	00000	00000	039	443334	3.50	H
11	614	73	S			45444	22223	00300	02000	00000	00000	131	533344	3.67	H
12	616	70	V	4.63	100	55445	22112	21111	00000	00000	00000	174	431344	3.17	M
13	641	77	V	5.38	121	45454	21111	11112	22100	00000	00000	424	111231	1.50	L
14	660	65	S			55553	22111	11112	22211	11100	00000	243	442544	3.83	H
15	672	77	S			55535	22211	23113	32100	00000	00000	301	211121	1.33	L
16	683	71	V	6.00	56	55443	21221	22222	22000	00000	00000	230	414234	3.00	M
17	702	69	S			55454	21111	20121	00010	00000	00000	158	433233	3.00	M
18	717	75	V	4.13	55	55553	32222	23332	22000	00000	00000	041	212223	2.00	L
19	730	69	S			45444	22100	22333	21200	00000	00000	394	313442	2.83	M
20	741	69	S			45353	21011	11001	00000	10000	00000	123	522553	3.67	H
21	763	77	S			55454	31112	23201	10000	00000	00000	303	211344	2.50	L
22	777	70	S			45441	11100	02001	00000	00000	00000	201	423244	3.17	H
23	784	73	V	5.00	57	55445	32222	24312	21232	00000	00000	244	221454	3.00	M
24	801	68	V	5.00	59	45454	11222	31330	00000	00000	00000	325	544445	4.33	H
25	815	81	V	4.00	51	45544	31221	34443	20100	00000	00000	049	111211	1.17	L
26	840	70	V	5.00	28	45544	11111	13113	03100	00000	00000	197	432533	3.33	H
27	843	70	S			54444	32110	11111	10000	00000	00000	029	222534	3.00	M
28	856	78	V	5.13	98	44555	43333	43233	44210	00000	00000	292	112112	1.33	L
29	871	76	S			44555	32123	34113	30000	00000	00000	328	223353	3.00	M
30	888	66	V	4.00	78	55545	32211	12111	11000	00000	00000	002	433524	3.50	H

*Frequency-variation type: "V" = vibrato, "S" = straight tone, "N" = non-periodic variation.

**Group: "H" = upper third of blend ratings, "M" = middle third of blend ratings, "L" = lower third of blend ratings.

TABLE XXX
ACOUSTICAL CHARACTERISTICS OF SOUNDS SUNG IN BLEND CONTEXT
VOWEL [a] PITCH A⁴ (440 HZ.)

Subject	Recording Order	Intensity (db)	Freq. type*	Vibrato Rate (cps)	Vibrato Extent (cents)	Relative Intensity of Partial (Rating 0-5)						Judging Order	Blend Rating 1-5 By Judge Number	Mean Rating	Group**
						Partial Number									
						1-5	6-10	11-15	16-20	21-25	26-30		123456		
1	462	85	V	4.75	105	55412	12031	00000	000			215	411133	2.17	L
2	473	79	V	6.00	24	54421	11111	10000	000			85	322344	3.00	H
3	495	77	V	4.63	47	55521	22232	00000	000			266	333245	3.33	H
4	498	70	V	4.38	36	54321	02221	00000	000			103	322324	2.67	M
5	512	82	V	5.50	79	55431	12222	20000	000			166	111111	1.00	L
6	533	74	V	5.13	102	55520	02220	00000	000			187	312144	2.50	M
7	548	74	N			55511	11311	10000	000			81	322233	2.50	M
8	566	82	S			55520	21212	10000	000			426	122344	2.67	M
9	583	75	V	4.63	83	55522	23333	10000	000			442	111242	1.83	L
10	594	75	S			54520	01211	00000	000			80	323344	3.00	H
11	613	76	V	5.13	53	54321	00000	00000	000			134	434254	3.67	H
12	629	74	S			54300	00000	00000	000			437	333223	2.67	M
13	632	77	V	5.25	84	55432	12222	10000	000			46	322223	2.33	L
14	658	72	S			55532	12232	10000	000			162	342343	3.17	H
15	672	75	V	5.50	32	55532	13232	00000	000			53	233333	2.83	M
16	678	75	V	5.88	60	55422	23221	00000	000			287	332213	2.33	M
17	691	76	V	5.13	38	55322	22321	11000	000			196	432342	3.00	H
18	716	84	S			55410	00111	00000	000			67	432333	3.00	H
19	721	70	V	5.50	67	55421	00111	00000	000			19	522324	3.00	H
20	742	73	V	5.25	56	55521	12342	20100	000			63	212132	1.83	L
21	755	82	S			55420	24100	00000	000			291	213224	2.33	M
22	767	74	N			54310	03100	00000	000			393	523343	3.33	H
23	793	76	V	5.00	59	55420	01110	10000	000			104	321323	2.33	L
24	799	77	V	5.50	58	54410	12321	00000	000			161	332342	2.83	M
25	813	79	V	4.50	85	55515	44000	00000	000			52	211122	1.50	L
26	833	73	V	5.13	39	54532	03333	10000	000			363	222323	2.33	L
27	854	77	N			55410	10000	00000	000			277	542315	3.33	H
28	870	90	V	4.75	108	55532	33343	10000	000			234	211123	1.67	L
29	875	74	V	5.50	72	55443	53300	00000	000			247	222344	2.83	M
30	896	76	V	4.88	53	44530	01000	00000	000			30	222233	2.33	L

*Frequency-variation type: "V" = vibrato, "S" = straight tone, "N" = non-periodic variation.

**Group: "H" = upper third of blend ratings, "M" = middle third of blend ratings, "L" = lower third of blend ratings.

TABLE XXXI
ACOUSTICAL CHARACTERISTICS OF SOUNDS SUNG IN BLEND CONTEXT
VOWEL [a] PITCH F⁵ (698 HZ.)

Subject	Recording Order	Intensity (db)	Freq. Type*	Vibrato Rate (cps)	Vibrato Extent (cents)	Relative Intensity of Partial (Rating 0-5)						Judging Order	Blend Rating 1-5 By Judge Number	Mean Rating	Group**
						Partial Number									
						1-5	6-10	11-15	16-20	21-25	26-30				
1	458	95	V	4.50	49	55031	20000	0				111	454455	4.50	H
2	478	95	S			54300	00000	0				165	553454	4.33	H
3	487	84	N			55301	30000	0				212	444334	3.67	H
4	496	91	V	5.00	69	55333	31000	0				293	354243	3.50	M
5	520	94	V	5.50	72	55111	00000	0				414	332223	2.50	L
6	540	88	V	5.25	103	55121	10000	0				180	422443	3.17	M
7	555	89	S			54001	00000	0				117	543353	3.83	H
8	569	93	S			55222	31000	0				144	343343	3.33	M
9	572	96	S			55132	20000	0				349	244333	3.17	L
10	599	93	S			55111	00000	0				188	343444	3.67	H
11	610	95	V	5.25	34	55211	00000	0				356	423123	2.50	L
12	625	96	V	5.50	43	55001	00000	0				65	544224	3.50	M
13	637	88	V	5.50	75	55203	20000	0				210	512132	2.33	L
14	654	85	S			55111	10000	0				112	442455	4.00	H
15	670	93	V	5.50	17	55334	20000	0				390	433424	3.33	M
16	684	92	V	6.00	38	55122	20000	0				330	343325	3.33	M
17	701	89	S			55222	10000	0				68	433333	3.17	L
18	711	90	S			54000	00000	0				141	433454	3.83	H
19	728	86	V	5.25	30	55021	10000	0				97	434434	3.67	H
20	744	92	V	5.50	41	55130	00000	0				257	344244	3.50	M
21	754	93	S			55221	00000	0				326	334334	3.33	M
22	771	89	S			55330	00000	0				140	444444	4.00	H
23	783	85	V	5.13	63	55221	20000	0				137	433342	3.17	M
24	800	92	V	5.75	64	55233	00000	0				386	323213	2.33	L
25	824	100	V	4.25	64	55243	30000	0				56	221414	2.33	L
26	838	91	V	5.38	34	55111	11000	0				157	224134	2.67	L
27	850	86	N			54000	00000	0				228	453444	4.00	H
28	861	103	V	5.13	123	55231	10000	0				354	111212	1.33	L
29	880	84	V	5.63	32	55112	20000	0				44	423345	3.50	M
30	891	86	V	5.00	40	45100	00000	0				371	322124	2.33	L

*Frequency-variation type: "V" = vibrato, "S" = straight tone, "N" = non-periodic variation.

**Group: "H" = upper third of blend ratings, "M" = middle third of blend ratings, "L" = lower third of blend ratings.

TABLE XXXII
ACOUSTICAL CHARACTERISTICS OF SOUNDS SUNG IN BLEND CONTEXT
VOWEL [O] PITCH C⁴ (261 HZ.)

Subject	Recording Order	Intensity (db)	Freq. type*	Vibrato Rate (cps)	Vibrato Extent (cents)	Relative Intensity of Partial (Rating 0-5)						Judging Order	Blend Rating 1-5 By Judge Number	Mean Rating	Group**
						Partial Number									
						1-5	6-10	11-15	16-20	21-25	26-30				
1	460	75	V	4.75	69	45544	21100	10001	00000	00000	00000	150	313232	2.33	L
2	470	70	V	4.50	74	45441	11100	00000	00000	00000	00000	254	334454	3.83	H
3	489	70	S			55444	11000	10001	10000	00000	00000	263	345553	4.17	H
4	504	69	N			45433	10000	11100	00000	00000	00000	167	555445	4.67	H
5	521	74	V	5.25	52	45443	11000	20000	21000	00000	00000	59	323533	3.17	M
6	526	72	N			55444	22332	23222	01000	00000	00000	360	354443	3.83	M
7	541	68	S			45440	00000	00000	00000	00000	00000	431	444433	3.67	M
8	556	72	S			45443	01210	31300	00000	00000	00000	142	212155	2.67	L
9	584	70	N			55443	31122	30131	01000	00000	00000	256	334454	3.83	M
10	587	72	N			45340	00000	00000	00000	00000	00000	82	434544	4.00	H
11	609	75	S			45430	00000	00000	00000	00000	00000	43	454554	4.50	H
12	627	73	V	4.38	29	45333	20002	10010	00000	00000	00000	172	233253	3.00	L
13	639	75	V	5.38	90	45441	11001	10022	00000	00000	00000	78	222543	3.00	L
14	657	70	S			55541	11100	01112	10000	00000	00000	199	343444	3.67	M
15	674	74	S			55443	22111	11101	12100	00000	00000	9	221514	2.50	L
16	689	72	V	5.75	50	55442	32101	00000	00000	00000	00000	185	322334	2.83	L
17	697	70	S			55332	11100	00010	00000	00000	00000	321	455254	4.17	H
18	707	72	V	4.75	73	45442	20000	11100	00000	00000	00000	32	232323	2.50	M
19	732	69	V	5.13	25	45443	11101	13332	21000	00000	00000	272	312413	2.33	L
20	750	69	N			55331	11000	00000	00000	00000	00000	366	445545	4.50	H
21	758	75	S			45443	11110	21002	00000	00000	00000	290	234453	3.50	M
22	779	71	S			45410	00000	00000	00000	00000	00000	198	454544	4.33	H
23	792	70	V	4.75	35	55441	10000	01110	00000	00000	00000	280	313443	3.00	L
24	802	70	V	5.25	42	45431	01000	00000	00000	00000	00000	128	333443	3.33	M
25	812	80	V	4.13	58	45454	21111	43331	10000	00000	00000	18	112423	2.17	L
26	830	72	S			45441	00000	00000	00000	00000	00000	398	525143	3.33	M
27	852	77	S			55433	20000	00000	00000	00000	00000	21	233445	3.50	M
28	867	78	V	5.25	119	45444	21111	31123	32100	00000	00000	16	111111	1.00	L
29	879	73	S			45541	01001	01001	10000	00000	00000	278	443554	4.17	H
30	893	68	V	4.50	51	55330	00000	00000	00000	00000	00000	274	434453	3.83	H

*Frequency-variation type: "V" = vibrato, "S" = straight tone, "N" = non-periodic variation.

**Group: "H" = upper third of blend ratings, "M" = middle third of blend ratings, "L" = lower third of blend ratings.

TABLE XXXIII
ACOUSTICAL CHARACTERISTICS OF SOUNDS SUNG IN BLEND CONTEXT
VOWEL [O] PITCH A⁴ (440 HZ.)

Subject	Recording Order	Intensity (db)	Freq. Type*	Vibrato Rate (cps)	Vibrato Extent (cents)	Relative Intensity of Partial (Rating 0-5)						Judging Order	Blend Rating 1-5 By Judge Number	Mean Rating	Group**
						Partial Number									
						1-5	6-10	11-15	16-20	21-25	26-30		123456		
1	456	84	V	4.50	108	54320	02001	00000	000			309	353234	3.33	M
2	468	82	V	4.25	36	54100	00000	00000	000			62	454244	3.83	H
3	490	76	S			54510	11110	00000	000			152	212244	2.50	L
4	506	75	V	4.88	46	55421	13221	10000	000			88	422333	2.83	M
5	511	83	V	5.25	77	54300	01111	00000	000			179	211133	1.83	L
6	527	75	V	5.38	80	54421	13221	00000	000			373	223243	2.67	L
7	542	74	V	5.00	85	55221	00110	00000	000			376	453233	3.33	M
8	558	85	S			55401	01400	00000	000			176	312254	2.83	M
9	573	82	V	4.50	33	45301	12231	00000	000			138	333334	3.17	M
10	593	78	N			54200	00000	00000	000			28	532335	3.50	H
11	612	77	V	5.50	53	54100	00000	00000	000			77	542444	3.83	H
12	617	79	V	5.25	51	54310	01020	00000	000			168	442344	3.50	H
13	645	79	V	5.50	108	55320	02230	00000	000			12	212312	1.83	L
14	656	70	S			55200	01020	00000	000			327	433234	3.17	M
15	675	75	N			55433	02312	00000	000			15	234244	3.17	M
16	690	78	V	5.88	47	55302	00000	00000	000			126	433343	3.33	H
17	699	75	N			55312	20100	00000	000			416	443243	3.33	M
18	710	81	S			55421	01100	00000	000			156	432453	3.50	H
19	733	74	V	5.25	53	54220	00110	00000	000			383	453434	3.83	H
20	746	75	V	5.50	54	54200	00000	00000	000			283	453334	3.67	H
21	761	81	S			55221	01010	00000	000			182	424343	3.33	M
22	769	79	S			54100	00000	00000	000			262	424354	3.67	H
23	791	75	V	4.75	38	55411	00000	00000	000			95	332233	2.67	L
24	810	78	V	5.38	60	55200	03310	00000	000			333	112223	1.83	L
25	821	76	V	4.38	58	55511	14330	00000	000			209	212132	1.83	L
26	828	76	V	5.00	40	54300	01122	00000	000			432	423344	3.33	M
27	853	73	N			55210	00200	00000	000			282	443212	2.67	L
28	869	86	V	4.88	107	55432	22343	20000	000			443	112212	1.50	L
29	885	75	V	5.25	61	55310	11111	00000	000			92	433444	3.67	H
30	890	74	V	4.88	85	55510	11110	00000	000			148	222244	2.67	L

*Frequency-variation type: "V" = vibrato, "S" = straight tone, "N" = non-periodic variation.

**Group: "H" = upper third of blend ratings, "M" = middle third of blend ratings, "L" = lower third of blend ratings.

TABLE XXXIV
ACOUSTICAL CHARACTERISTICS OF SOUNDS SUNG IN BLEND CONTEXT
VOWEL [O] PITCH F⁵ (698 HZ.)

Subject	Recording Order	Intensity (db)	Freq. type*	Vibrato Rate (cps)	Vibrato Extent (cents)	Relative Intensity of Partial (Rating 0-5)						Judging Order	Blend Rating 1-5 By Judge Number	Mean Rating	Group**
						Partial Number									
						1-5	6-10	11-15	16-20	21-25	26-30				
1	454	96	V	5.50	84	55341	22000	0				113	311134	2.17	L
2	474	96	S			55411	00000	0				265	354254	3.83	H
3	483	87	N			54121	20000	0				55	454234	3.67	M
4	502	95	V	5.75	68	54333	30000	0				343	223114	2.17	L
5	524	97	V	5.38	60	55203	00000	0				132	443333	3.33	M
6	532	87	V	5.13	75	55211	00000	0				400	322111	1.67	L
7	547	87	S			54101	00000	0				300	444424	3.67	H
8	563	100	N			55333	12000	0				323	224214	2.50	L
9	581	92	S			55130	00000	0				237	344444	3.83	H
10	600	88	S			54100	00000	0				51	544334	3.83	H
11	603	96	V	5.50	57	54010	00000	0				260	434233	3.17	M
12	620	96	V	4.88	26	54000	00000	0				236	344434	3.67	H
13	643	89	V	5.38	71	54202	10000	0				372	323113	2.17	L
14	649	90	V	5.00	19	55222	00000	0				70	554334	4.00	H
15	663	94	S			55333	11000	0				430	123433	2.67	L
16	687	91	V	5.75	39	55222	20000	0				90	323333	2.83	L
17	696	89	N			55212	00000	0				435	433225	3.17	M
18	712	95	S			55010	00000	0				276	454314	3.50	M
19	725	88	V	5.50	64	55111	00000	0				100	433424	3.33	M
20	740	91	S			55030	00000	0				253	344444	3.83	H
21	751	87	S			55111	00000	0				423	353244	3.50	M
22	770	90	S			54120	00000	0				241	354443	3.83	H
23	794	89	V	5.25	52	55111	10000	0				17	454434	4.00	H
24	806	91	V	5.50	56	55121	00000	0				93	444333	3.50	M
25	814	99	V	4.38	58	55111	10000	0				370	111213	1.50	L
26	832	91	V	4.75	32	55110	00000	0				368	254334	3.50	M
27	855	88	S			54100	00000	0				391	444233	3.33	M
28	868	103	V	4.88	107	55011	10000	0				203	131415	2.50	L
29	881	84	V	5.38	34	54000	10000	0				357	323333	2.83	L
30	894	84	V	5.25	49	55010	10000	0				194	454343	3.83	H

*Frequency-variation type: "V" = vibrato, "S" = straight tone, "N" = non-periodic variation.

**Group: "H" = upper third of blend ratings, "M" = middle third of blend ratings, "L" = lower third of blend ratings.

TABLE XXXV
ACOUSTICAL CHARACTERISTICS OF SOUNDS SUNG IN BLEND CONTEXT
VOWEL [U] PITCH C⁴ (261 Hz.)

Subject	Recording Order	Intensity (db)	Freq. type*	Vibrato Rate (cps)	Vibrato Extent (cents)	Relative Intensity of Partial (Rating 0-5)						Judging Order	Blend Rating 1-5 By Judge Number	Mean Rating	Group**
						Partial Number									
						1-5	6-10	11-15	16-20	21-25	26-30				
1	452	73	V	5.00	74	45342	20000	10000	00000	00000	00000	155	333242	2.83	L
2	467	70	N			45331	10000	00000	00000	00000	00000	355	223445	3.33	M
3	491	70	N			45431	20000	00000	00000	00000	00000	116	544454	4.33	
4	497	66	N			45400	00000	00000	00000	00000	00000	139	444444	4.00	H
5	522	73	V	5.38	69	45432	10000	10000	00000	00000	00000	91	333433	3.17	L
6	537	68	V	5.14	48	55313	10000	00000	00000	00000	00000	227	524334	3.50	M
7	552	67	N			55220	00000	00000	00000	00000	00000	279	534443	3.83	M
8	568	67	S			55431	00001	11000	00000	00000	00000	192	344544	4.00	H
9	574	69	S			55443	11110	20131	11000	00000	00000	107	133243	2.67	L
10	595	71	N			55331	00000	00000	00000	00000	00000	369	524443	3.67	M
11	611	70	V	5.25	42	55421	00000	00000	00000	00000	00000	271	433334	3.33	L
12	624	65	V	4.50	39	55220	00000	00000	00000	00000	00000	208	543444	4.00	H
13	633	73	V	5.50	64	45420	10000	00000	00000	00000	00000	214	244232	2.83	L
14	646	66	S			55411	00000	00000	00000	00000	00000	109	544544	4.33	H
15	661	73	V	5.25	37	55443	11100	10000	01000	00000	00000	66	234545	3.83	M
16	677	71	V	5.88	41	55442	20000	00000	00000	00000	00000	380	223232	2.33	L
17	692	67	S			55130	00010	00000	00000	00000	00000	299	434443	3.67	M
18	708	71	V	4.88	147	55552	11010	10001	10000	00000	00000	364	111111	1.00	L
19	722	67	N			55300	00000	00000	00000	00000	00000	415	534542	3.83	M
20	739	70	N			54011	00000	00000	00000	00000	00000	251	534353	3.83	M
21	760	71	S			55441	01101	00000	00000	00000	00000	410	224444	3.33	L
22	772	65	S			54300	00000	00000	00000	00000	00000	310	544444	4.17	H
23	787	69	V	5.00	55	55241	00000	00000	00000	00000	00000	248	334555	4.17	H
24	805	67	V	5.00	51	54340	00000	00000	00000	00000	00000	178	544554	4.50	H
25	823	73	V	4.25	47	45442	00010	00000	00000	00000	00000	3	122433	2.50	L
26	827	69	V	5.25	33	45331	00002	00000	00000	00000	00000	264	454444	4.17	H
27	847	68	S			55331	00000	00000	00000	00000	00000	408	244444	3.67	M
28	858	75	V	4.88	103	45442	10002	10022	12100	00000	00000	11	111122	1.33	L
29	874	69	S			55410	00000	00000	00000	00000	00000	317	544453	4.17	H
30	898	66	V	4.75	79	55443	30010	00000	00000	00000	00000	1	542433	3.50	M

*Frequency-variation type: "V" = vibrato, "S" = straight tone, "N" = non-periodic variation.

**Group: "H" = upper third of blend ratings, "M" = middle third of blend ratings, "L" = lower third of blend ratings.

TABLE XXXVI
ACOUSTICAL CHARACTERISTICS OF SOUNDS SUNG IN BLEND CONTEXT
VOWEL [U] PITCH A⁴ (440 Hz.)

Subject	Recording Order	Intensity (db)	Freq. type*	Vibrato Rate (cps)	Vibrato Extent (cents)	Relative Intensity of Partial (Rating 0-5)						Judging Order	Blend Rating 1-5 By Judge Number	Mean Rating	Group**
						Partial Number									
						1-5	6-10	11-15	16-20	21-25	26-30				
1	455	85	V	4.50	71	54300	00000	00000	000			375	343233	3.00	M
2	477	83	S			53200	00000	00000	000			84	353454	4.00	H
3	492	84	N			54300	00010	00000	000			217	322244	2.83	M
4	500	82	V	4.63	69	52200	00000	00000	000			275	323233	2.67	L
5	516	82	V	5.38	101	54310	03110	00000	000			258	212142	2.00	L
6	530	79	V	4.88	66	54310	00000	00000	000			269	522244	3.17	H
7	545	79	V	4.88	82	54100	00000	00000	000			378	432224	2.83	M
8	567	85	N			54300	00000	00000	000			211	421244	2.83	M
9	571	80	N			45411	13232	00000	000			388	223234	2.67	L
10	598	77	N			54200	00000	00000	000			224	342343	3.17	H
11	601	84	V	5.75	84	54000	00000	00000	000			83	442433	3.33	H
12	621	82	V	5.38	55	53000	00000	00000	000			350	442334	3.33	H
13	636	80	V	5.00	79	55100	10000	00000	000			105	522433	3.17	H
14	650	67	V	5.50	32	54310	10100	00000	000			13	544532	1.17	L
15	673	78	V	5.75	33	54411	02110	00000	000			98	222443	2.83	M
16	686	80	V	5.75	58	55221	10000	00000	000			382	343233	3.00	M
17	698	76	S			54210	00000	00000	000			297	332234	2.83	L
18	709	81	V	5.00	151	55310	00000	00000	000			304	551232	3.00	M
19	724	73	V	5.50	56	54000	00000	00000	000			36	431234	2.83	M
20	749	78	V	5.13	56	53000	00000	00000	000			396	332233	2.67	L
21	752	82	V	5.00	26	54110	00000	00000	000			334	322333	2.67	L
22	766	81	S			52000	00000	00000	000			229	343345	3.67	H
23	790	75	V	4.88	53	54300	00010	00000	000			50	342235	3.17	H
24	808	85	V	4.63	46	54200	10000	00000	000			298	333224	2.83	L
25	819	81	V	4.38	85	54410	31110	00000	000			64	222323	2.33	L
26	837	80	S			54100	00000	00000	000			448	453343	3.67	H
27	846	81	N			52000	00000	00000	000			154	422343	3.00	M
28	862	88	V	5.00	121	54422	32243	30000	000			183	111122	1.33	L
29	876	77	V	5.25	60	55200	11000	00000	000			270	523255	3.67	H
30	886	73	V	5.13	64	53300	00000	00000	000			345	452233	3.17	M

*Frequency-variation type: "V" = vibrato, "S" = straight tone, "N" = non-periodic variation.

**Group: "H" = upper third of blend ratings, "M" = middle third of blend ratings, "L" = lower third of blend ratings.

TABLE XXXVII
ACOUSTICAL CHARACTERISTICS OF SOUNDS SUNG IN BLEND CONTEXT
VOWEL [U] PITCH F⁵ (698 HZ.)

Subject	Recording Order	Intensity (db)	Freq. type*	Vibrato Rate (cps)	Vibrato Extent (cents)	Relative Intensity of Partial (Rating 0-5)						Judging Order	Blend Rating 1-5 By Judge Number	Mean Rating	Group**
						Partial Number									
						1-5	6-10	11-15	16-20	21-25	26-30		123456		
1	457	94	V	5.00	63	55332	21100	0				268	344253	3.50	H
2	466	90	S			54310	00000	0				143	444544	4.17	H
3	488	82	N			54100	00000	0				89	523432	3.17	M
4	507	91	V	5.13	51	54232	10000	0				130	444244	3.67	H
5	513	98	V	5.25	47	55121	10000	0				45	142224	2.50	L
6	535	86	V	5.25	77	55321	00000	0				324	323114	2.33	L
7	550	87	S			55011	00000	0				340	434214	3.00	M
8	559	94	S			54111	00000	0				74	233422	2.67	L
9	577	94	S			45311	00000	0				352	314324	2.83	M
10	591	92	S			54110	00000	0				136	344353	3.67	H
11	602	95	V	5.63	48	55220	00000	0				24	434413	3.17	M
12	619	96	V	5.25	31	54001	00000	0				160	453333	3.50	H
13	634	89	V	5.38	103	55101	10000	0				40	324324	3.00	M
14	653	90	S			55111	00000	0				249	444333	3.50	H
15	671	95	S			55444	21000	0				351	214223	2.33	L
16	676	93	V	6.00	45	55111	00000	0				22	422212	2.17	L
17	700	87	S			55221	00000	0				358	342214	2.67	M
18	713	96	N			54111	00000	0				159	443444	3.83	H
19	727	87	V	5.38	46	55121	10000	0				450	244443	3.50	M
20	738	88	V	5.50	58	55010	00000	0				99	333424	3.17	M
21	759	92	S			55111	00000	0				73	433344	3.50	H
22	778	90	S			53110	00000	0				436	344444	3.83	H
23	785	89	V	5.13	50	53110	00000	0				86	222433	2.67	L
24	804	92	V	5.38	67	54120	00000	0				5	433323	3.00	M
25	825	96	V	4.25	92	55121	10000	0				47	211223	1.83	L
26	826	91	S			54010	00000	0				71	325433	3.33	M
27	849	92	S			54100	00000	0				392	324232	2.67	L
28	864	101	V	4.75	104	55111	10000	0				295	121223	1.83	L
29	872	88	V	5.88	52	54111	11000	0				216	453344	3.83	H
30	895	83	V	5.13	33	55011	00000	0				26	423123	2.50	L

*Frequency-variation type: "V" = vibrato, "S" = straight tone, "N" = non-periodic variation.

**Group: "H" = upper third of blend ratings, "M" = middle third of blend ratings, "L" = lower third of blend ratings.

TABLE XXXVIII
ACOUSTICAL CHARACTERISTICS OF SOUNDS SUNG IN BLEND CONTEXT
VOWEL [ɛ] PITCH C⁴ (261 HZ.)

Subject	Recording Order	Intensity (db)	Freq. Type*	Vibrato Rate (cps)	Vibrato Extent (cents)	Relative Intensity of Partial (Rating 0-5)						Judging Order	Blend Rating 1-5 By Judge Number	Mean Rating	Group**
						Partial Number									
						1-5	6-10	11-15	16-20	21-25	26-30				
1	459	76	V	4.75	73	45331	22321	20000	00000	00000	00000	353	413443	3.17	H
2	469	70	V	4.50	78	45422	22110	00000	00000	00000	00000	175	523443	3.50	M
3	482	71	V	4.50	39	45443	34423	31111	31000	00000	00000	101	413243	2.83	M
4	499	67	V	4.00	76	45411	34101	10010	00000	00000	00000	205	424333	3.17	H
5	517	72	V	5.38	53	44444	44433	44112	21110	00000	00000	344	132212	1.83	L
6	534	69	V	5.50	90	55411	11100	00000	00000	00000	00000	7	322223	2.33	M
7	749	69	N			55132	23211	21001	00000	00000	00000	186	422343	3.00	M
8	564	76	N			45444	34434	41122	33222	22222	22222	419	212232	2.00	L
9	580	68	S			55433	44333	42133	11111	11111	11111	48	533344	3.67	H
10	586	72	N			55222	12101	10000	00000	00000	00000	418	423344	3.33	H
11	607	72	S			45423	34321	11111	10000	00000	00000	332	232221	2.00	L
12	623	75	V	5.13	44	45333	34221	11010	10000	00000	00000	286	323242	2.67	M
13	631	73	V	5.00	134	55544	55423	41111	21000	00000	00000	346	111112	1.17	L
14	651	67	S			55423	34312	22111	11111	11111	11111	403	213442	2.67	M
15	669	73	N			55434	44412	33211	11111	11111	11111	445	112412	1.83	L
16	679	73	V	5.75	55	55433	44111	31111	00111	11000	00000	449	222243	2.50	M
17	694	70	N			55433	34333	20121	11111	11111	11111	8	324323	2.83	M
18	720	74	V	5.00	68	55433	33212	11111	00000	00000	00000	177	433344	3.50	H
19	729	70	V	5.25	39	55333	44343	11232	10000	00000	00000	171	211142	1.83	L
20	737	70	V	5.00	31	55333	33133	10012	00000	00000	00000	440	324432	3.00	H
21	756	71	S			55432	34311	31111	11000	00000	00000	190	543243	3.50	H
22	780	70	S			45310	22100	00000	00000	00000	00000	377	444432	3.50	H
23	786	72	V	5.00	46	55444	44422	21112	11100	00000	00000	381	112332	2.00	L
24	803	68	V	5.00	45	55444	44112	21122	11000	00000	00000	319	323244	3.00	M
25	820	77	V	4.00	44	45433	44222	42331	10000	00000	00000	399	111211	1.17	L
26	829	71	V	5.00	31	45433	31322	31112	11100	00000	00000	226	414343	3.17	H
27	841	77	S			55432	33412	21111	10000	00000	00000	407	112443	2.50	M
28	860	76	V	4.88	96	45534	45333	23233	33200	00000	00000	33	111212	1.33	L
29	873	70	V	4.88	50	55443	44334	41122	22210	00000	00000	397	212232	2.00	L
30	899	68	V	5.00	81	55311	23100	10000	00000	00000	00000	315	423243	3.00	M

*Frequency-variation type: "V" = vibrato, "S" = straight tone, "N" = non-periodic variation.

**Group: "H" = upper third of blend ratings, "M" = middle third of blend ratings, "L" = lower third of blend ratings.

TABLE XXXIX
ACOUSTICAL CHARACTERISTICS OF SOUNDS SUNG IN BLEND CONTEXT
VOWEL [E] PITCH A⁴ (440 HZ.)

Subject	Recording Order	Intensity (db)	Freq. Type*	Vibrato Rate (cps)	Vibrato Extent (cents)	Relative Intensity of Partial (Rating 0-5)						Judging Order	Blend Rating 1-5 By Judge Number	Mean Rating	Group**
						Partial Number									
						1-5	6-10	11-15	16-20	21-25	26-30				
1	464	82	V	5.00	97	54344	42120	00000	000			96	213122	1.83	L
2	476	78	N			54421	31011	00000	000			285	434345	3.83	H
3	493	77	V	4.00	39	54444	43233	00000	000			206	434344	3.67	H
4	501	74	V	4.50	80	54453	33131	00000	000			213	333333	3.00	L
5	518	81	V	5.38	81	54453	34232	00000	000			202	212233	2.17	L
6	536	72	V	5.25	60	54442	01000	00000	000			387	525444	4.00	H
7	551	73	N			53311	02010	10000	000			135	444353	3.83	H
8	557	84	S			55423	33111	00000	000			193	322433	2.83	L
9	579	80	N			55444	43142	11000	000			308	233445	3.50	M
10	592	78	V	4.25	30	53441	10100	00000	000			367	322355	3.33	M
11	605	78	V	4.88	50	54343	31110	00000	000			87	324542	3.33	M
12	618	72	V	4.00	47	54331	10000	00000	000			261	324354	3.50	M
13	644	77	V	5.50	84	55551	41430	00000	000			76	112322	1.83	L
14	659	67	N			54411	11122	00000	000			305	352453	3.67	M
15	666	70	V	5.88	31	54444	34311	00000	000			313	254344	3.67	M
16	680	72	V	5.75	58	55341	23221	00000	000			118	323344	3.17	M
17	695	72	S			54441	10000	00000	000			114	434454	4.00	H
18	718	74	V	5.00	63	54351	32000	00000	000			4	434544	4.00	H
19	734	71	V	5.50	51	53222	30010	00000	000			189	453444	4.00	H
20	745	72	V	5.25	62	53241	41011	10000	000			146	254353	3.67	H
21	762	77	S			55541	22110	00000	000			413	121345	2.67	L
22	775	74	S			52322	00010	00000	000			385	425442	3.50	M
23	781	73	V	5.00	46	54440	13111	10000	000			57	445445	4.33	H
24	796	77	V	5.38	42	54441	12411	10000	000			122	214344	3.00	L
25	822	76	V	4.25	62	54441	44130	00000	000			204	111223	1.66	L
26	836	74	V	5.25	31	54423	12231	00000	000			231	213545	3.33	M
27	848	73	N			54440	01110	00000	000			446	324444	3.50	M
28	866	83	V	5.00	110	55453	43333	20000	000			439	111111	1.00	L
29	882	74	V	4.75	55	53431	42111	00000	000			318	433454	3.83	H
30	897	71	V	5.50	62	55541	11100	00000	000			329	223235	2.83	L

*Frequency-variation type: "V" = vibrato, "S" = straight tone, "N" = non-periodic variation.

**Group: "H" = upper third of blend ratings, "M" = middle third of blend ratings, "L" = lower third of blend ratings.

TABLE XL
ACOUSTICAL CHARACTERISTICS OF SOUNDS SUNG IN BLEND CONTEXT
VOWEL [E] PITCH F⁵ (698 HZ.)

Subject	Recording Order	Intensity (db)	Freq. type*	Vibrato Rate (cps)	Vibrato Extent (cents)	Relative Intensity of Partial (Rating 0-5)						Judging Order	Blend Rating 1-5 By Judge Number	Mean Rating	Group**
						Partial Number									
						1-5	6-10	11-15	16-20	21-25	26-30				
1	451	94	V	5.00	83	55130	20000	0				336	314324	2.83	M
2	479	94	S			54200	00000	0				246	334344	3.50	H
3	486	87	V	4.13	41	54211	20000	0				23	433213	2.67	M
4	510	90	V	5.00	70	52342	10000	0				37	434233	3.17	H
5	525	99	V	5.13	56	54343	20000	0				259	222142	2.17	L
6	531	86	V	5.13	72	55212	21000	0				312	331222	2.17	L
7	546	89	N			54100	00000	0				163	333442	3.17	H
8	570	93	S			54231	10000	0				219	343243	3.17	H
9	578	90	S			55420	11000	0				379	343222	2.67	L
10	589	93	N			54221	00000	0				284	333135	3.00	M
11	615	96	S			54310	00000	0				374	323233	2.67	L
12	628	96	S			54421	10000	0				255	323243	2.83	M
13	635	94	V	5.50	95	55333	30000	0				164	221222	1.83	L
14	648	89	V	5.00	44	55120	00000	0				348	344244	3.50	H
15	662	90	V	5.75	52	55455	41100	0				361	212234	2.33	L
16	681	95	V	5.75	53	55221	00000	0				365	433213	2.67	M
17	705	84	N			54210	00000	0				102	332344	3.17	H
18	715	100	V	5.38	40	54100	00000	0				444	344233	3.17	H
19	735	87	V	5.25	42	54110	00000	0				307	342224	2.83	M
20	743	89	V	5.25	42	53120	00000	0				147	343344	3.50	H
21	753	94	S			55221	00000	0				181	333354	3.50	L
22	774	89	S			54441	00000	0				331	334134	3.00	M
23	782	89	V	5.25	83	54210	00000	0				281	332332	2.67	L
24	797	94	V	5.63	82	54230	00000	0				124	242344	3.17	H
25	818	94	V	4.25	75	54432	10000	0				302	112123	1.67	L
26	839	88	V	5.00	35	54120	11000	0				434	224325	3.00	N
27	851	88	N			54201	00000	0				25	333224	2.83	M
28	857	100	V	4.75	102	54421	00000	0				428	121222	1.67	L
29	883	86	V	5.75	35	55031	00000	0				404	224343	3.00	M
30	892	84	V	5.25	57	55311	10000	0				322	221123	1.83	L

*Frequency-variation type: "V" = vibrato, "S" = straight tone, "N" = non-periodic variation.

**Group: "H" = upper third of blend ratings, "M" = middle third of blend ratings, "L" = lower third of blend ratings.

TABLE XLI
ACOUSTICAL CHARACTERISTICS OF SOUNDS SUNG IN BLEND CONTEXT
VOWEL [ɛ] PITCH C⁴ (261 HZ.)

Subject	Recording Order	Intensity (db)	Freq. Type*	Vibrato Rate (cps)	Vibrato Extent (cents)	Relative Intensity of Partial (Rating 0-5)						Judging Order	Blend Rating 1-5 By Judge Number	Mean Rating	Group**
						Partial Number									
						1-5	6-10	11-15	16-20	21-25	26-30				
1	461	69	V	5.00	138	44111	13333	21232	21000	00000	00000	58	322242	2.50	M
2	471	69	N			54311	00122	10010	00000	00000	00000	235	444444	4.00	H
3	485	69	N			55101	12122	31013	10000	00000	00000	347	532223	2.83	M
4	509	66	V	4.00	28	54122	22333	11133	31000	00000	00000	38	534554	4.33	H
5	519	70	V	5.38	71	54221	22234	44444	43210	00000	00000	191	211232	1.83	L
6	539	68	V	4.50	86	44110	00010	01000	00000	00000	00000	35	523222	2.67	M
7	554	69	V	5.00	33	55011	12111	11001	00000	00000	00000	427	323432	2.83	M
8	562	70	S			55311	01143	11112	10100	00000	00000	120	222232	2.17	L
9	575	71	V	4.00	46	55431	31343	41344	22210	00000	00000	250	211222	1.67	L
10	596	72	V	5.00	24	43000	00000	00000	00000	00000	00000	54	522232	2.67	M
11	606	71	V	5.25	84	55311	33433	20010	00000	00000	00000	60	222111	1.50	L
12	630	68	V	4.50	36	54211	22333	31113	11000	00000	00000	225	213233	2.33	L
13	642	71	V	5.25	115	55111	11133	30001	10000	00000	00000	402	212221	1.67	L
14	652	67	S			54111	01331	31132	20000	00000	00000	222	534333	3.50	H
15	664	73	S			54122	11124	43322	42200	00000	00000	119	111221	1.33	L
16	682	71	V	6.13	45	55111	44444	11142	01000	00000	00000	406	112122	1.50	L
17	693	67	S			54110	11021	00010	00000	00000	00000	115	422333	2.83	M
18	719	70	V	5.00	61	54133	22344	22133	33300	11210	00010	127	221244	2.50	M
19	723	66	V	5.50	40	54100	00010	00000	00000	00000	00000	289	441241	2.67	M
20	748	69	V	5.00	35	54101	00013	31001	00000	00000	00000	273	511123	2.17	L
21	757	67	S			54111	11121	22111	11000	00000	00000	31	444443	3.83	H
22	773	65	N			54100	11100	00000	00000	00000	00000	233	524332	3.17	H
23	795	69	V	5.00	55	54110	00011	10000	00000	00000	00000	422	334334	3.33	H
24	798	66	N			54110	10011	10000	00000	00000	00000	20	433223	2.83	M
25	817	70	V	4.00	50	45121	21343	32221	10000	00000	00000	61	333243	3.00	H
26	835	70	V	5.00	29	55211	01242	21111	01110	00000	00000	72	444443	3.83	H
27	847	70	N			54111	11003	33100	01000	00000	00000	294	453143	3.33	H
28	865	75	V	5.00	103	45323	23444	43244	44300	00000	00000	405	111211	1.17	L
29	884	68	N			55221	11244	31113	11110	00000	00000	238	222254	2.83	M
30	889	66	V	4.63	73	54100	01010	10000	00000	00000	00000	129	544553	4.33	H

*Frequency-variation type: "V" = vibrato, "S" = straight tone, "N" = non-periodic variation.

**Group: "H" = upper third of blend ratings, "M" = middle third of blend ratings, "L" = lower third of blend ratings.

TABLE XLII
ACOUSTICAL CHARACTERISTICS OF SOUNDS SUNG IN BLEND CONTEXT
VOWEL [i] PITCH A⁴ (440 HZ.)

Subject	Recording Order	Intensity (db)	Freq. type*	Vibrato Rate (cps)	Vibrato Extent (cents)	Relative Intensity of Partial (Rating 0-5)						Judging Order	Blend Rating 1-5 By Judge Number	Mean Rating	Group**
						Partial Number									
						1-5	6-10	11-15	16-20	21-25	26-30				
1	465	80	V	4.75	113	53131	11000	00000	000			106	122222	1.83	L
2	475	82	V	4.25	28	53132	10000	00000	000			149	223343	2.83	L
3	484	75	V	4.38	39	52011	11001	00000	000			401	434322	3.00	M
4	503	81	V	4.50	62	50113	11011	10000	000			296	244234	3.17	M
5	515	80	V	5.50	91	53334	34321	10000	000			125	111122	1.33	L
6	528	80	V	5.13	46	53111	11000	00000	000			412	334423	3.17	M
7	543	77	N			54131	00000	00000	000			121	434444	3.83	H
8	565	84	N			54134	31111	00000	000			34	323453	3.33	M
9	582	80	N			54114	40010	00000	000			153	324354	3.50	H
10	588	82	V	4.75	20	53110	00000	00000	000			447	454344	4.00	H
11	608	81	V	5.75	70	53231	10000	00000	000			341	343224	3.00	M
12	622	82	V	5.00	60	52212	20010	00000	000			339	332323	2.67	L
13	638	81	V	5.13	79	53333	30000	00000	000			316	223233	2.50	L
14	647	6	N			53213	21000	00000	000			314	353334	3.50	H
15	667	75	V	5.63	47	54334	32111	00000	000			429	122424	2.50	L
16	685	79	V	6.25	67	53240	11010	00000	000			6	224334	3.00	M
17	703	74	S			53111	00000	00000	000			252	423245	3.33	M
18	714	80	V	4.75	50	53212	10000	00000	000			79	343434	3.25	M
19	726	75	V	5.13	51	51211	00000	00000	000			409	344334	3.50	H
20	736	78	V	5.50	78	52222	31010	00000	000			342	343323	3.00	M
21	765	82	S			52101	00000	00000	000			438	554444	4.33	H
22	776	81	S			50130	00000	00000	000			151	234345	3.50	H
23	789	77	V	5.13	60	54100	00000	00000	000			242	333444	3.50	H
24	809	83	V	5.25	92	52112	20201	00000	000			411	223323	2.50	L
25	816	81	V	4.00	87	51224	43110	00000	000			94	231222	2.00	L
26	831	81	V	5.25	36	52202	00120	00000	000			224	224444	3.33	M
27	844	75	N			52112	11000	00000	000			42	354334	3.67	H
28	859	85	V	5.00	125	54234	34112	00000	000			169	111133	1.67	L
29	877	75	V	5.00	32	52232	31010	00000	000			389	214223	2.33	L
30	887	74	V	5.25	66	52220	00000	00000	000			239	343345	3.67	H

*Frequency-variation type: "V" = vibrato, "S" = straight tone, "N" = non-periodic variation.

**Group: "H" = upper third of blend ratings, "M" = middle third of blend ratings, "L" = lower third of blend ratings.

TABLE XLIII
ACOUSTICAL CHARACTERISTICS OF SOUNDS SUNG IN BLEND CONTEXT
VOWEL [i] PITCH F⁵ (698 HZ.)

Subject	Recording Order	Intensity (db)	Freq. Type*	Vibrato Rate (cps)	Vibrato Extent (cents)	Relative Intensity of Partial (Rating 0-5)						Judging Order	Blend Rating 1-5 By Judge Number	Mean Rating	Group**
						Partial Number									
						1-5	6-10	11-15	16-20	21-25	26-30				
1	463	88	V	4.75	73	53330	00000	0				421	214434	3.00	M
2	472	8	S			54300	00000	0				362	334233	3.00	M
3	494	87	V	4.13	25	54441	11000	0				75	344333	3.33	H
4	505	93	V	5.25	70	54431	10100	0				195	322233	2.50	L
5	523	95	V	5.38	49	54542	20000	0				108	123234	2.50	L
6	538	84	V	5.13	123	54312	00000	0				170	422432	2.83	M
7	553	88	N			54200	10000	0				10	444343	3.67	H
8	561	91	S			54341	00000	0				306	112342	2.17	L
9	576	92	V	4.50	39	54430	11000	0				221	333233	2.83	L
10	590	91	S			54310	00000	0				200	332342	2.83	L
11	604	96	V	5.50	35	54320	00000	0				245	355343	3.83	H
12	626	95	V	5.25	36	53410	00000	0				337	434224	3.17	H
13	640	90	V	5.50	90	55240	00000	0				441	112412	1.83	L
14	655	84	S			53200	00000	0				173	343354	3.67	H
15	665	93	S			54444	21000	0				15	225343	3.17	M
16	688	93	V	5.50	50	54310	00000	0				223	423432	3.00	M
17	704	83	S			54210	00000	0				145	342542	3.33	M
18	706	98	V	5.25	90	53310	00000	0				133	332343	3.00	M
19	731	85	V	5.25	45	54100	00000	0				417	344234	3.33	H
20	747	88	V	5.50	46	54120	00000	0				433	333344	3.33	H
21	764	96	S			54130	00000	0				207	323345	3.33	H
22	768	89	S			52200	00000	0				359	344224	3.17	M
23	788	87	V	5.13	53	53421	10000	0				338	444235	3.67	H
24	807	91	V	5.50	72	53220	00000	0				320	242324	2.83	M
25	811	93	V	4.25	105	54532	10000	0				232	111322	1.67	L
26	834	87	V	5.38	35	53310	00000	0				267	233343	3.00	M
27	842	88	S			54320	00000	0				384	324323	2.83	L
28	863	98	V	4.75	50	54431	10000	0				184	111224	1.83	L
29	878	87	V	5.13	41	54141	00000	0				425	244333	3.17	H
30	900	82	V	5.38	41	54200	00000	0				335	224324	2.83	L

*Frequency-variation type: "V" = vibrato, "S" = straight tone, "N" = non-periodic variation.

**Group: "H" = upper third of blend ratings, "M" = middle third of blend ratings, "L" = lower third of blend ratings.

APPENDIX H

ACOUSTICAL CHARACTERISTICS OF A STRATIFIED RANDOM SAMPLE
OF VOCAL SOUNDS EVALUATED A SECOND TIME TO ASSESS THE
RELIABILITY OF THE DATA GATHERING PROCEDURES

TABLE XLIV

ACOUSTICAL CHARACTERISTICS OF A STRATIFIED RANDOM SAMPLE
OF VOCAL SOUNDS EVALUATED A SECOND TIME TO ASSESS THE
RELIABILITY OF THE DATA GATHERING PROCEDURES

Subject	Recording Order	Context*	Vowel	Pitch	Vibrato Rate** (cps)	Vibrato Extent*** (cents)	Relative Intensity of Partial (Rating 0-5)					
							Partial Number					
							1-5	6-10	11-15	16-20	21-25	26-30
23	343	S	α	C	5.25	37	45445	33123	34443	33430	00000	00000
29	426	S	α	C	5.50	47	55554	31122	33131	11000	00000	00000
4	508	B	α	C	(N)	(N)	45444	11111	13333	12100	00000	00000
12	616	B	α	C	5.00	96	55445	22113	32232	11000	00000	00000
27	401	S	α	A	4.50	32	54541	11110	00000	000		
1	010	S	α	A	5.75	123	55543	44343	00000	000		
3	495	B	α	A	4.75	47	55531	22242	00000	000		
28	870	B	α	A	4.63	107	55542	33343	10000	000		
28	419	S	α	F	4.50	102	55022	10000	0			
20	290	S	α	F	5.75	48	55111	00000	0			
6	540	B	α	F	5.25	103	55121	10000	0			
25	824	B	α	F	4.50	65	55143	30000	0			
2	024	S	o	C	5.00	85	45441	11111	00000	00000	00000	00000
22	317	S	o	C	(N)	(N)	45441	01001	10010	00000	00000	00000
26	830	B	o	C	(S)	(S)	45441	00000	00000	00000	00000	00000
11	609	B	o	C	(S)	(S)	45430	00000	00000	00000	00000	00000
13	184	S	o	A	5.50	125	55310	13222	00000	000		
17	243	S	o	A	6.00	38	55422	22411	00000	000		
23	791	B	o	A	4.75	37	55411	00000	00000	000		
2	468	B	o	A	4.75	34	54100	00000	00000	000		
8	120	S	o	F	(N)	(N)	54221	21000	0			
7	101	S	o	F	5.75	71	55101	10000	0			
25	814	B	o	F	4.25	57	55121	20000	0			
1	454	B	o	F	5.25	81	55341	22000	0			
20	292	S	u	C	5.25	51	54331	00010	00000	00000	00000	00000
11	151	S	u	C	(N)	(N)	55431	10010	00000	10000	00000	00000
6	537	B	u	C	4.25	46	55212	00000	00000	00000	00000	00000
18	708	B	u	C	5.00	145	55531	10101	00110	00000	00000	00000
8	112	S	u	A	5.25	19	55211	01100	00000	000		
4	055	S	u	A	5.50	71	54411	43420	00000	100		

*"S" = solo context; "B" = blend context.

**"S" = straight tone; "N" = nonperiodic variation.

***"S" = straight tone; "N" = nonperiodic variation.

TABLE XLIV--Continued

Subject	Recording Order	Context*	Vowel	Pitch	Vibrato Rate** (cps)	Vibrato Extent*** (cents)	Relative Intensity of Partial (Rating 0-5)					
							Partial Number					
							1-5	6-10	11-15	16-20	21-25	26-30
13	636	B	u	A	5.00	80	55100	10000	00000	000		
17	698	B	u	A	(S)	(S)	54210	00000	00000	000		
15	214	S	u	F	5.63	62	55445	11000	0			
18	256	S	u	F	6.25	193	55321	01000	0			
27	849	B	u	F	(S)	(S)	54100	00000	0			
11	602	B	u	F	5.50	47	55210	00000	0			
12	172	S	e	C	5.25	34	45333	34331	11121	10000	00000	00000
4	057	S	e	C	5.00	53	45444	55334	43444	21110	00000	00000
3	482	B	e	C	5.00	38	55443	33333	32111	21000	00000	00000
16	679	B	e	C	6.00	57	55433	44111	31111	00100	11110	00000
9	129	S	e	A	5.50	38	45444	40242	10000	010		
19	278	S	e	A	5.25	50	53334	41011	00000	000		
14	659	B	e	A	(N)	(N)	54411	22122	00000	000		
3	493	B	e	A	4.63	38	54444	43233	00000	000		
1	012	S	e	F	5.75	108	55532	22000	0			
26	383	S	e	F	5.25	45	54221	10000	0			
13	635	B	e	F	5.50	94	54333	30000	0			
11	615	B	e	F	(S)	(S)	54310	00000	0			
13	188	S	i	C	5.25	79	55311	11343	21113	20000	00000	00000
19	280	S	i	C	5.25	48	54111	11343	31123	30000	00000	00000
27	847	B	i	C	(N)	(N)	54111	11003	33100	01000	00000	00000
24	798	B	i	C	(N)	(N)	54110	10011	10000	00000	00000	00000
25	368	S	i	A	4.25	64	51334	43221	00000	000		
15	225	S	i	A	5.88	89	53334	54444	10000	000		
4	503	B	i	A	4.50	64	50113	11011	10000	000		
2	475	B	i	A	4.75	27	53132	10000	00000	000		
25	373	S	i	F	4.63	71	54543	30000	0			
26	388	S	i	F	5.50	49	54441	31000	0			
3	494	B	i	F	4.25	31	54441	11000	0			
29	878	B	i	F	5.25	41	54241	00000	0			

*"S" = solo context; "B" = blend context.

**"S" = straight tone; "N" = nonperiodic variation.

***"S" = straight tone; "N" = nonperiodic variation.

APPENDIX I

TABLES COMPARING GROUP-MEAN DIFFERENCES OF SPECTRA FOR
VOCAL SOUNDS PRODUCED IN SOLO AND BLEND CONTEXTS

TABLE XLV

GROUP-MEAN DIFFERENCES OF SPECTRA FOR VOCAL SOUNDS
PRODUCED IN SOLO AND BLEND CONTEXTS
ON THE VOWEL [a]

Partial Number	Pitch Level														
	C4 (261 Hz.)					A4 (440 Hz.)					F5 (698 Hz.)				
	Intensity Rating X		Degrees of Freedom	t-Value	Probability	Intensity Rating X		Degrees of Freedom	t-Value	Probability	Intensity Rating X*		Degrees of Freedom	t-Value	Probability**
	Solo	Blend				Solo	Blend				Solo	Blend			
1	4.27	4.47	29	-1.80	.083	4.90	4.97	29	-1.44	.161	5.00	4.97	29	99.00	.001
2	4.73	4.73	29	0.00	1.000	4.57	4.70	29	-1.44	.161	4.73	4.86	29	-1.07	.293
3	4.37	4.20	29	1.54	.134	4.33	4.27	29	0.49	.625	2.10	1.43	29	3.96	.001
4	4.40	4.33	29	0.44	.662	2.67	2.00	29	3.01	.005	2.43	1.60	29	3.40	.002
5	4.07	3.97	29	0.62	.541	1.77	1.13	29	3.07	.005	2.23	1.33	29	5.57	.001
6	2.67	2.20	29	2.63	.014	2.00	1.13	29	3.50	.002	1.50	1.07	29	1.99	.056
7	1.87	1.57	29	1.51	.142	3.13	1.83	29	5.11	.001	0.37	0.10	29	1.68	.103
8	1.70	1.33	29	2.08	.046	3.07	1.67	29	5.56	.001	0.07	0.00	29	99.00	.001
9	1.67	1.37	29	1.66	.107	2.83	1.56	29	4.75	.001	0.00	0.00	29	0.00	1.000
10	1.73	1.40	29	1.98	.057	1.93	1.10	29	3.22	.003	0.00	0.00	29	0.00	1.000
11	2.27	1.67	29	2.90	.007	1.27	0.43	29	3.40	.002	0.00	0.00	29	0.00	1.000
12	2.67	1.90	29	3.80	.001	0.47	0.03	29	3.07	.005					
13	2.47	1.60	29	4.56	.001	0.23	0.03	29	1.99	.056					
14	2.57	1.47	29	4.56	.001	0.10	0.00	29	99.00	.001					
15	2.07	1.67	29	1.72	.097	0.00	0.00	29	0.00	1.000					
16	1.77	1.30	29	1.92	.065	0.07	0.00	29	99.00	.001					
17	1.63	1.10	29	2.19	.036	0.07	0.00	29	99.00	.001					
18	1.07	0.67	29	1.99	.056	0.07	0.00	29	99.00	.001					
19	0.87	0.27	29	4.04	.001										
20	0.33	0.17	29	1.15	.258										
21	0.27	0.13	29	1.16	.255										
22	0.17	0.07	29	1.14	.264										
23	0.17	0.07	29	1.14	.264										
24	0.17	0.03	29	1.28	.211										
25	0.13	0.03	29	1.14	.264										
26	0.13	0.03	29	1.14	.264										
27	0.10	0.03	29	0.81	.423										
28	0.13	0.03	29	1.14	.264										
29	0.13	0.03	29	1.14	.264										
30	0.13	0.03	29	1.14	.264										

*Intensity rating on a scale of 0-5.

**The probability of the difference between the group means occurring by chance if no difference existed in the population means; calculated by a t-test of dependent means; each group N = 30.

TABLE XLVI

GROUP-MEAN DIFFERENCES OF SPECTRA FOR VOCAL SOUNDS
PRODUCED IN SOLO AND BLEND CONTEXTS
ON THE VOWEL [O]

Partial Number	Pitch Level														
	C4 (261 Hz.)					A4 (440 Hz.)					F5 (698 Hz.)				
	Intensity Rating x		Degrees of Freedom	t-Value	Probability	Intensity Rating x		Degrees of Freedom	t-Value	Probability	Intensity Rating x*		Degrees of Freedom	t-Value	Probability**
	Solo	Blend				Solo	Blend				Solo	Blend			
1	4.20	4.37	29	-1.72	.096	4.97	4.97	29	0.00	1.000	5.00	5.00	29	0.00	1.000
2	5.00	5.00	29	0.00	1.000	4.57	4.60	29	-0.37	.712	4.73	4.67	29	0.70	.489
3	4.17	3.90	29	2.28	.030	3.53	2.97	29	2.66	.012	2.03	1.33	29	3.53	.001
4	3.87	3.67	29	1.03	.312	1.53	1.00	29	2.50	.018	2.13	1.37	29	3.43	.002
5	2.47	2.03	29	1.75	.091	1.10	.60	29	3.18	.003	1.73	1.03	29	3.25	.003
6	1.73	1.10	29	3.74	.001	1.40	.37	29	5.48	.001	1.47	.53	29	4.47	.001
7	1.07	.73	29	2.07	.048	2.47	1.07	29	5.04	.001	.40	.17	29	1.88	.070
8	.80	.50	29	1.87	.071	2.40	1.17	29	3.73	.001	.07	0.00	29	99.00	.001
9	.87	.37	29	2.81	.009	2.30	1.03	29	4.47	.001	0.00	0.00	29	0.00	.001
10	1.20	.43	29	3.36	.002	1.27	.43	29	3.88	.001	0.00	0.00	29	0.00	.001
11	1.60	.90	29	3.17	.004	.57	.17	29	2.11	.043	0.00	0.00	29	0.00	.001
12	1.30	.60	29	2.57	.015	.13	0.00	29	99.00	.001					
13	1.50	.60	29	3.35	.002	.07	0.00	29	99.00	.001					
14	1.70	.63	29	3.82	.001	.03	0.00	29	99.00	.001					
15	1.23	.63	29	2.83	.008	0.00	0.00	29	0.00	1.000					
16	.77	.37	29	2.05	.050	0.00	0.00	29	0.00	1.000					
17	.63	.30	29	2.07	.048	0.00	0.00	29	0.00	1.000					
18	.37	.10	29	1.61	.118	0.00	0.00	29	0.00	1.000					
19	.23	.03	29	1.53	.136										
20	.07	.07	29	0.00	1.000										
21	.03	.03	29	0.00	1.000										
22	.03	0.00	29	99.00	.001										
23	.03	0.00	29	99.00	.001										
24	.03	0.00	29	99.00	.001										
25	.03	0.00	29	99.00	.001										
26	.03	0.00	29	99.00	.001										
27	.03	0.00	29	99.00	.001										
28	.03	0.00	29	99.00	.001										
29	.03	0.00	29	99.00	.001										
30	.03	0.00	29	99.00	.001										

*Intensity rating on a scale of 0-5.

**The probability of the difference between the group means occurring by chance if no difference existed in the population means; calculated by a t-test of dependent means; each group N = 30.

TABLE XLVII
 GROUP MEAN DIFFERENCES OF SPECTRA FOR VOCAL SOUNDS
 PRODUCED IN SOLO AND BLEND CONTEXTS
 ON THE VOWEL [U]

Partial Number	Pitch Level														
	C4 (261 Hz.)					A4 (440 Hz.)					F5 (698 Hz.)				
	Intensity Rating X		Degrees of Freedom	t-Value	Probability	Intensity Rating X		Degrees of Freedom	t-Value	Probability	Intensity Rating X		Degrees of Freedom	t-Value	Probability**
	Solo	Blend				Solo	Blend				Solo	Blend			
1	4.83	4.70	29	1.68	.103	5.00	4.97	29	99.00	.001	5.00	4.97	29	99.00	<.001
2	4.90	4.90	29	0.00	1.000	4.07	3.83	29	2.04	.050	4.67	4.57	29	.77	.448
3	3.53	3.30	29	1.37	.182	2.57	2.03	29	2.24	.033	1.67	1.30	29	2.26	.032
4	3.33	2.70	29	2.62	.014	.63	.43	29	1.53	.136	1.83	1.33	29	2.48	.019
5	1.97	1.17	29	4.00	.001	.27	.17	29	.90	.375	1.20	.83	29	2.08	.046
6	.93	.57	29	2.01	.054	.90	.40	29	2.24	.033	.67	.37	29	1.30	.204
7	.40	.13	29	3.25	.003	.97	.40	29	1.90	.067	.20	.10	29	1.36	.184
8	.47	.10	29	2.26	.032	1.13	.27	29	3.26	.003	0.00	.03	29	99.00	<.001
9	.67	.17	29	3.34	.002	.53	.40	29	.89	.380	0.00	0.00	29	0.00	1.000
10	.77	.20	29	2.98	.006	.20	.23	29	-.30	.769	0.00	0.00	29	0.00	1.000
11	.60	.27	29	1.90	.067	0.00	.10	29	99.00	.001	0.00	0.00	29	0.00	1.000
12	.50	.03	29	2.54	.017	0.00	0.00	29	0.00	1.000					
13	.73	.03	29	3.43	.002	0.00	0.00	29	0.00	1.000					
14	.87	.17	29	3.17	.004	0.00	0.00	29	0.00	1.000					
15	.47	.13	29	2.57	.016	0.00	0.00	29	0.00	1.000					
16	.53	.10	29	2.64	.013	.03	0.00	29	99.00	.001					
17	.47	.13	29	2.28	.030	0.00	0.00	29	0.00	1.000					
18	.13	.03	29	1.80	.083	0.00	0.00	29	0.00	1.000					
19	.07	0.00	29	99.00	.001										
20	0.00	0.00	29	0.00	1.000										
21	0.00	0.00	29	0.00	1.000										
22	0.00	0.00	29	0.00	1.000										
23	0.00	0.00	29	0.00	1.000										
24	0.00	0.00	29	0.00	1.000										
25	0.00	0.00	29	0.00	1.000										
26	0.00	0.00	29	0.00	1.000										
27	0.00	0.00	29	0.00	1.000										
28	0.00	0.00	29	0.00	1.000										
29	.07	0.00	29	0.00	.001										
30	0.00	0.00	29	0.00	1.000										

*Intensity rating on a scale of 0-5.

**The probability of the difference between the group means occurring by chance if no difference existed in the population means; calculated by a t-test of dependent means; each group N = 30.

TABLE XLVIII

GROUP MEAN DIFFERENCES OF SPECTRA FOR VOCAL SOUNDS
PRODUCED IN SOLO AND BLEND CONTEXTS
ON THE VOWEL [ɛ]

Partial Number	Pitch Level														
	C4 (261 Hz.)					A4 (440 Hz.)					F5 (698 Hz.)				
	Intensity Rating $\bar{x}$ Context		Degrees of Freedom	t-Value	Probability	Intensity Rating $\bar{x}$ Context		Degrees of Freedom	t-Value	Probability	Intensity Rating $\bar{x}$ Context		Degrees of Freedom	t-Value	Probability**
	Solo	Blend				Solo	Blend				Solo	Blend			
1	4.27	4.60	29	-3.34	.002	4.90	5.00	29	99.00	.001	5.00	5.00	29	0.00	1.000
2	4.87	4.97	29	-1.36	.184	4.23	4.00	29	1.88	.070	4.27	4.23	29	.24	.813
3	4.10	3.70	29	2.84	.008	4.00	3.73	29	1.86	.073	3.33	2.67	29	4.55	.001
4	3.47	2.83	29	3.47	.002	4.27	3.57	29	3.75	.001	3.30	2.00	29	5.20	.001
5	3.47	2.70	29	3.43	.002	3.07	1.83	29	5.80	.001	1.63	.93	29	4.37	.001
6	3.97	3.10	29	5.07	.001	3.57	2.27	29	5.02	.001	1.50	.77	29	4.10	.001
7	4.10	3.43	29	3.44	.002	3.20	1.83	29	5.34	.001	.47	.20	29	1.68	.103
8	3.23	2.50	29	3.52	.001	2.87	1.17	29	6.57	.001	.07	.03	29	1.00	.326
9	2.57	1.67	29	3.97	.001	2.90	1.47	29	5.49	.001	.03	0.00	29	99.00	.001
10	3.00	1.87	29	4.75	.001	1.97	.73	29	4.64	.001	0.00	0.00	29	0.00	1.000
11	2.90	2.10	29	3.45	.002	.87	.23	29	4.29	.001	0.00	0.00	29	0.00	1.000
12	2.07	1.03	29	4.55	.001	.40	.03	29	2.80	.009					
13	1.80	.83	29	5.12	.001	.27	0.00	29	99.00	.001					
14	2.07	1.17	29	4.96	.001	.30	0.00	29	99.00	.001					
15	2.17	1.13	29	5.15	.001	.17	0.00	29	99.00	.001					
16	1.67	.93	29	4.10	.001	.23	0.00	29	99.00	.001					
17	1.23	.63	29	3.53	.001	.10	0.00	29	99.00	.001					
18	.97	.47	29	2.92	.007	.10	0.00	29	99.00	.001					
19	.73	.30	29	2.90	.007										
20	.60	.23	29	3.00	.005										
21	.53	.23	29	2.34	.026										
22	.50	.23	29	2.28	.030										
23	.50	.20	29	2.52	.017										
24	.47	.20	29	2.28	.030										
25	.40	.23	29	1.54	.134										
26	.37	.23	29	1.28	.211										
27	.33	.23	29	.90	.375										
28	.37	.23	29	1.16	.255										
29	.33	.23	29	.90	.375										
30	.33	.23	29	.90	.375										

*Intensity rating on a scale of 0-5.

**The probability of the difference between the group means occurring by chance if no difference existed in the population means; calculated by a t-test of dependent means; each group N = 30.

TABLE XLIX
GROUP-MEAN DIFFERENCES OF SPECTRA FOR VOCAL SOUNDS
PRODUCED IN SOLO AND BLEND CONTEXTS
ON THE VOWEL [ɛ]

Partial Number	Pitch Level														
	C4 (261 Hz.)					A4 (440 Hz.)					F5 (698 Hz.)				
	Intensity Rating $\bar{x}$ Context		Degrees of Freedom	t-Value	Probability	Intensity Rating $\bar{x}$ Context		Degrees of Freedom	t-Value	Probability	Intensity Rating $\bar{x}$ Context		Degrees of Freedom	t-Value	Probability**
	Solo	Blend				Solo	Blend				Solo	Blend			
1	4.90	4.83	29	1.00	.326	5.00	5.00	29	0.00	1.000	5.00	5.00	29	0.00	1.000
2	4.50	4.33	29	1.72	.096	2.47	2.57	29	-.62	.541	4.00	3.73	29	2.50	.018
3	2.20	1.43	29	4.17	.001	2.60	1.57	29	5.01	.001	3.83	2.87	29	4.82	.001
4	1.67	1.13	29	3.00	.005	2.60	1.83	29	2.57	.016	3.33	1.97	29	6.15	.001
5	1.43	.93	29	3.34	.002	3.20	1.87	29	4.68	.001	1.40	.53	29	4.56	.001
6	2.03	1.10	29	5.21	.001	3.13	1.47	29	5.85	.001	1.23	.37	29	4.42	.001
7	2.20	1.27	29	4.88	.001	2.00	.77	29	5.18	.001	.47	.10	29	2.80	.009
8	3.13	1.57	29	7.18	.001	1.77	.33	29	5.90	.001	.03	.03	29	0.00	1.000
9	3.60	2.33	29	4.54	.001	2.07	.47	29	6.35	.001	0.00	0.00	29	0.00	1.000
10	3.40	2.20	29	4.47	.001	1.20	.27	29	5.41	.001	0.00	0.00	29	0.00	1.000
11	2.93	1.93	29	3.58	.001	.43	.07	29	2.16	.039	0.00	0.00	29	0.00	1.000
12	2.47	1.07	29	5.66	.001	.13	0.00	29	99.00	.001					
13	2.20	.87	29	5.88	.001	.03	0.00	29	99.00	.001					
14	2.67	1.30	29	4.85	.001	0.00	0.00	29	0.00	1.000					
15	2.67	1.43	29	4.43	.001	0.00	0.00	29	0.00	1.000					
16	1.93	1.03	29	3.03	.005	0.00	0.00	29	0.00	1.000					
17	1.47	.73	29	2.71	.011	0.00	0.00	29	0.00	1.000					
18	.73	.50	29	1.02	.315	0.00	0.00	29	0.00	1.000					
19	.30	.13	29	1.41	.169										
20	.10	0.00	29	99.00	.001										
21	.10	.03	29	.81	.423										
22	0.00	.03	29	99.00	.001										
23	0.00	.07	29	99.00	.001										
24	0.00	.03	29	99.00	.001										
25	.03	0.00	29	99.00	.001										
26	.03	0.00	29	99.00	.001										
27	0.00	0.00	29	0.00	1.000										
28	0.00	0.00	29	0.00	1.000										
29	0.00	.03	29	99.00	.001										
30	.07	0.00	29	99.00	.001										

*Intensity rating on a scale of 0-5.

**The probability of the difference between the group means occurring by chance if no difference existed in the population means; calculated by a t-test of dependent means; each group N = 30.

APPENDIX J

TABLES COMPARING GROUP-MEAN DIFFERENCES OF SPECTRA FOR
VOCAL SOUNDS IDENTIFIED AS BLENDING WELL AND
BLENDING POORLY WITH A UNISON ENSEMBLE

TABLE L

GROUP-MEAN DIFFERENCES OF SPECTRA FOR VOCAL SOUNDS
IDENTIFIED AS BLENDING WELL AND POORLY WITH A
UNISON ENSEMBLE ON THE VOWEL [a]

Partial Number	Pitch Level														
	C4 (261 Hz.)					A4 (440 Hz.)					F5 (698 Hz.)				
	Intensity Rating $\bar{x}$		Degrees of Freedom	t-Value	Probability	Intensity Rating $\bar{x}$		Degrees of Freedom	t-Value	Probability	Intensity Rating $\bar{x}$		Degrees of Freedom	t-Value	Probability**
	Good	Poor				Good	Poor				Good	Poor			
1	4.40	4.40	18	0.00	1.000	5.00	4.90	18	1.00	.331	5.00	4.90	18	1.00	.331
2	4.90	4.70	18	1.10	.288	4.60	4.80	18	-.95	.335	4.60	5.00	18	-2.45	.025
3	4.10	4.40	18	-.85	.408	4.00	4.60	18	-1.96	.065	1.10	1.60	18	-1.08	.301
4	4.20	4.60	18	-1.10	.288	1.80	2.30	18	-1.52	.145	1.00	1.80	18	-1.35	.194
5	3.40	4.20	18	-2.03	.058	.80	1.70	18	-1.75	.096	.60	1.70	18	-2.95	.011
6	1.50	2.80	18	-3.88	.001	.70	1.30	18	-1.21	.243	.70	1.00	18	-.63	.534
7	1.40	1.70	18	-1.12	.279	1.10	2.30	18	-2.61	.018	0.00	.10	18	-1.00	.331
8	1.10	1.50	18	-1.04	.314	1.30	1.70	18	-.77	.450	0.00	0.00	18	0.00	1.000
9	1.20	1.50	18	-1.00	.331	1.20	2.20	18	-1.70	.107	0.00	0.00	18	0.00	1.000
10	1.10	1.70	18	-1.58	.132	.90	1.60	18	-1.51	.148	0.00	0.00	18	0.00	1.000
11	1.00	2.10	18	-2.70	.015	.20	.90	18	-2.60	.018	0.00	0.00	18	0.00	1.000
12	1.40	2.20	18	-1.49	.154	.10	0.00	18	1.00	.331					
13	1.40	1.80	18	-.77	.449	0.00	.10	18	-1.00	.331					
14	1.00	1.90	18	-1.54	.142	0.00	0.00	18	0.00	1.000					
15	1.20	2.10	18	-1.89	.076	0.00	0.00	18	0.00	1.000					
16	.50	2.10	18	-4.15	.001	0.00	0.00	18	0.00	1.000					
17	1.00	1.60	18	-1.15	.264	0.00	0.00	18	0.00	1.000					
18	.50	.90	18	-1.12	.276	0.00	0.00	18	0.00	1.000					
19	.10	.20	18	-.60	.556										
20	.10	0.00	18	1.00	.331										
21	.20	0.00	18	1.50	.151										
22	.10	0.00	18	1.00	.331										
23	.10	0.00	18	1.00	.331										
24	0.00	0.00	18	0.00	1.000										
25	0.00	0.00	18	0.00	1.000										
26	0.00	0.00	18	0.00	1.000										
27	0.00	0.00	18	0.00	1.000										
28	0.00	0.00	18	0.00	1.000										
29	0.00	0.00	18	0.00	1.000										
30	0.00	0.00	18	0.00	1.000										

*Intensity rating on a scale of 0-5.

**The probability of the difference between the group means occurring by chance if no difference existed in the population means; calculated by a t-test of independent means; each group N = 10.

TABLE LI
GROUP-MEAN DIFFERENCES OF SPECTRA FOR VOCAL SOUNDS
IDENTIFIED AS BLENDING WELL AND POORLY WITH A
UNISON ENSEMBLE ON THE VOWEL [O]

Partial Number	Pitch Level														
	C4 (261 Hz.)					A4 (440 Hz.)					F5 (698 Hz.)				
	Intensity Rating $\bar{x}$		Degrees of Freedom	t-Value	Probability	Intensity Rating $\bar{x}$		Degrees of Freedom	t-Value	Probability	Intensity Rating $\bar{x}^*$		Degrees of Freedom	t-Value	Probability**
	Group					Group					Group				
	Good	Poor				Good	Poor				Good	Poor			
1	4.40	4.30	18	.45	.660	5.00	5.00	18	0.00	1.000	5.00	5.00	18	0.00	1.000
2	5.00	5.00	18	0.00	1.000	4.30	4.70	18	-1.85	.081	4.60	4.70	18	-.45	.660
3	3.70	3.90	18	-.85	.411	2.20	3.70	18	-3.05	.007	1.10	1.90	18	-1.49	.152
4	3.20	4.00	18	-2.45	.025	.60	1.20	18	-1.52	.146	1.30	1.80	18	-.87	.396
5	1.20	2.80	18	-2.81	.012	.30	.50	18	-.65	.526	.50	1.70	18	-2.98	.008
6	.50	1.60	18	-3.50	.003	.10	.60	18	-2.06	.060	.20	1.20	18	-3.54	.003
7	.50	1.00	18	-1.86	.079	.30	1.70	18	-3.11	.010	0.00	.50	18	-1.86	.079
8	.20	.70	18	-1.99	.062	.30	1.80	18	-4.16	.001	0.00	0.00	18	0.00	1.000
9	.10	.40	18	-1.57	.135	.40	1.60	18	-2.50	.022	0.00	0.00	18	0.00	1.000
10	.10	.80	18	-3.13	.006	.10	.50	18	-1.24	.242	0.00	0.00	18	0.00	1.000
11	.20	1.50	18	-2.90	.014	0.00	.20	18	-1.00	.331	0.00	0.00	18	0.00	1.000
12	.20	1.00	18	-2.06	.064	0.00	0.00	18	0.00	1.000					
13	.10	1.20	18	-2.57	.028	0.00	0.00	18	0.00	1.000					
14	.10	1.20	18	-2.74	.021	0.00	0.00	18	0.00	1.000					
15	.20	1.00	18	-2.23	.046	0.00	0.00	18	0.00	1.000					
16	.20	.70	18	-1.39	.191	0.00	0.00	18	0.00	1.000					
17	0.00	.50	18	-1.86	.079	0.00	0.00	18	0.00	1.000					
18	0.00	.20	18	-1.50	.151	0.00	0.00	18	0.00	1.000					
19	0.00	0.00	18	0.00	1.000										
20	0.00	0.00	18	0.00	1.000										
21	0.00	0.00	18	0.00	1.000										
22	0.00	0.00	18	0.00	1.000										
23	0.00	0.00	18	0.00	1.000										
24	0.00	0.00	18	0.00	1.000										
25	0.00	0.00	18	0.00	1.000										
26	0.00	0.00	18	0.00	1.000										
27	0.00	0.00	18	0.00	1.000										
28	0.00	0.00	18	0.00	1.000										
29	0.00	0.00	18	0.00	1.000										
30	0.00	0.00	18	0.00	1.000										

*Intensity rating on a scale of 0-5.

**The probability of the difference between the group means occurring by chance if no difference existed in the population means; calculated by a t-test of independent means; each group N = 10.

TABLE LII

GROUP-MEAN DIFFERENCES OF SPECTRA FOR VOCAL SOUNDS
IDENTIFIED AS BLENDING WELL AND POORLY WITH A
UNISON ENSEMBLE ON THE VOWEL [U]

Partial Number	Pitch Level														
	C4 (261 Hz.)					A4 (440 Hz.)					F5 (698 Hz.)				
	Intensity Rating $\bar{x}$		Degrees of Freedom	t-Value	Probability	Intensity Rating $\bar{x}$		Degrees of Freedom	t-Value	Probability	Intensity Rating $\bar{x}^*$		Degrees of Freedom	t-Value	Probability**
	Good	Poor				Good	Poor				Good	Poor			
1	4.70	4.50	18	.88	.388	5.00	4.90	18	1.00	.331	5.00	5.00	18	0.00	1.000
2	4.80	5.00	18	-1.50	.151	3.80	3.80	18	0.00	1.000	4.20	4.80	18	-2.50	.022
3	3.30	4.00	18	-2.33	.031	1.40	2.50	18	-1.94	.068	1.40	1.40	18	0.00	1.000
4	2.10	3.60	18	-2.63	.017	.10	.80	18	-3.13	.006	1.30	1.50	18	-.44	.665
5	.50	1.70	18	-3.88	.001	0.00	.30	18	-1.41	.177	.90	1.10	18	-.48	.639
6	.20	.90	18	-2.28	.035	.20	.90	18	-1.74	.109	.40	.50	18	-.32	.754
7	0.00	.30	18	-1.96	.065	.10	.90	18	-1.91	.085	.20	.10	18	.60	.556
8	0.00	.20	18	-1.50	.151	0.00	.70	18	-2.69	.015	.10	0.00	18	1.00	.331
9	0.00	.30	18	-1.96	.065	.10	.90	18	-1.71	.112	0.00	0.00	18	0.00	1.000
10	.30	.30	18	0.00	1.000	0.00	.50	18	-1.46	.160	0.00	0.00	18	0.00	1.000
11	.10	.60	18	-2.06	.060	0.00	.30	18	-1.00	.331	0.00	0.00	18	0.00	1.000
12	.10	0.00	18	1.00	.331	0.00	0.00	18	0.00	1.000					
13	0.00	.10	18	-1.00	.331	0.00	0.00	18	0.00	1.000					
14	0.00	.50	18	-1.46	.160	0.00	0.00	18	0.00	1.000					
15	0.00	.40	18	-1.81	.087	0.00	0.00	18	0.00	1.000					
16	0.00	.30	18	-1.96	.065	0.00	0.00	18	0.00	1.000					
17	0.00	.30	18	-1.41	.177	0.00	0.00	18	0.00	1.000					
18	0.00	.10	18	-1.00	.331	0.00	0.00	18	0.00	1.000					
19	0.00	0.00	18	0.00	1.000										
20	0.00	0.00	18	0.00	1.000										
21	0.00	0.00	18	0.00	1.000										
22	0.00	0.00	18	0.00	1.000										
23	0.00	0.00	18	0.00	1.000										
24	0.00	0.00	18	0.00	1.000										
25	0.00	0.00	18	0.00	1.000										
26	0.00	0.00	18	0.00	1.000										
27	0.00	0.00	18	0.00	1.000										
28	0.00	0.00	18	0.00	1.000										
29	0.00	0.00	18	0.00	1.000										
30	0.00	0.00	18	0.00	1.000										

*Intensity rating on a scale of 0-5.

**The probability of the difference between the group means occurring by chance if no difference existed in the population means; calculated by a t-test of independent means; each group N = 10.

TABLE LIIT

GROUP-MEAN DIFFERENCES OF SPECTRA FOR VOCAL SOUNDS
IDENTIFIED AS BLENDING WELL AND POORLY WITH A
UNISON ENSEMBLE ON THE VOWEL [E]

Partial Number	Pitch Level														
	C4 (261 Hz.)					A4 (440 Hz.)					F5 (698 Hz.)				
	Intensity Rating $\bar{x}$		Degrees of Freedom	t-Value	Probability	Intensity Rating $\bar{x}$		Degrees of Freedom	t-Value	Probability	Intensity Rating $\bar{x}^*$		Degrees of Freedom	t-Value	Probability**
	Good	Poor				Good	Poor				Good	Poor			
1	4.50	4.50	18	0.00	1.000	5.00	5.00	18	0.00	1.000	5.00	5.00	18	0.00	1.000
2	5.00	4.90	18	1.00	.331	3.60	4.50	18	-3.86	.001	3.90	4.50	18	-1.86	.080
3	5.50	4.10	18	-2.09	.051	3.40	4.20	18	-2.40	.027	1.70	3.20	18	-4.57	.001
4	2.40	3.40	18	-2.89	.010	3.30	4.20	18	-1.83	.083	1.70	2.30	18	-.95	.357
5	2.00	3.60	18	-4.31	.001	1.40	2.10	18	-1.38	.186	.40	1.70	18	-2.31	.039
6	2.60	3.90	18	-4.04	.001	2.30	2.90	18	-.94	.362	.20	1.50	18	-2.75	.019
7	2.70	4.20	18	-4.16	.001	1.50	2.50	18	-2.07	.053	0.00	.50	18	-2.24	.038
8	2.90	3.40	18	-3.90	.001	.40	1.90	18	-3.24	.005	0.00	.10	18	-1.00	.331
9	1.30	2.50	18	-2.64	.017	.90	2.00	18	-2.40	.027	0.00	0.00	18	0.00	1.000
10	1.40	2.70	18	-2.87	.010	.70	.80	18	-.23	.824	0.00	0.00	18	0.00	1.000
11	1.60	2.90	18	-2.20	.041	.30	.30	18	0.00	1.000	0.00	0.00	18	0.00	1.000
12	.50	1.80	18	-3.07	.007	0.00	0.00	18	0.00	1.000					
13	.40	1.50	18	-3.97	.001	0.00	0.00	18	0.00	1.000					
14	.80	1.80	18	-2.43	.026	0.00	0.00	18	0.00	1.000					
15	.90	1.70	18	-1.96	.066	0.00	0.00	18	0.00	1.000					
16	.30	1.70	18	-4.64	.001	0.00	0.00	18	0.00	1.000					
17	.30	1.20	18	-2.31	.040	0.00	0.00	18	0.00	1.000					
18	.20	.90	18	-2.28	.040	0.00	0.00	18	0.00	1.000					
19	.10	.50	18	-1.63	.128										
20	.10	.30	18	-.85	.411										
21	.10	.30	18	-.85	.411										
22	.10	.30	18	-.85	.411										
23	.10	.30	18	-.85	.411										
24	.10	.30	18	-.85	.411										
25	.10	.30	18	-.85	.411										
26	.10	.30	18	-.85	.411										
27	.10	.30	18	-.85	.411										
28	.10	.30	18	-.85	.411										
29	.10	.30	18	-.85	.411										
30	.10	.30	18	-.85	.411										

*Intensity rating on a scale of 0-5.

**The probability of the difference between the group means occurring by chance if no difference existed in the population means; calculated by a t-test of independent means; each group N = 10.

TABLE LIV

GROUP-MEAN DIFFERENCES OF SPECTRA FOR VOCAL SOUNDS
IDENTIFIED AS BLENDING WELL AND POORLY WITH A
UNISON ENSEMBLE ON THE VOWEL [i]

Partial Number	Pitch Level														
	C4 (261 Hz.)					A4 (440 Hz.)					F5 (698 Hz.)				
	Intensity Rating $\bar{x}$		Degrees of Freedom	t-Value	Probability	Intensity Rating $\bar{x}$		Degrees of Freedom	t-Value	Probability	Intensity Rating $\bar{x}^*$		Degrees of Freedom	t-Value	Probability**
	Good	Poor				Good	Poor				Good	Poor			
1	4.90	4.90	18	0.00	1.000	5.00	5.00	18	0.00	1.000	5.00	5.00	18	0.00	1.000
2	4.20	4.60	18	-1.90	.074	2.50	2.70	18	-.38	.707	3.80	4.10	18	-1.80	.089
3	1.30	2.10	18	-1.96	.066	1.30	2.00	18	-2.33	.031	2.10	3.50	18	-2.75	.013
4	1.00	1.40	18	-1.18	.255	1.30	2.50	18	-2.79	.012	1.80	2.70	18	-1.39	.181
5	.80	1.30	18	-1.71	.105	1.10	2.80	18	-2.92	.009	.30	.70	18	-1.33	.202
6	.70	1.80	18	-2.24	.038	.70	2.50	18	-3.44	.003	.30	.60	18	-1.12	.279
7	.90	1.80	18	-2.10	.056	.20	1.50	18	-2.41	.036	.10	.10	18	0.00	1.000
8	1.40	2.30	18	-1.45	.163	0.00	.80	18	-2.45	.025	0.00	.10	18	-1.00	.331
9	2.00	3.10	18	-1.94	.068	.10	.70	18	-2.55	.024	0.00	0.00	18	0.00	1.000
10	1.60	3.40	18	-4.44	.001	0.00	.50	18	-2.24	.038	0.00	0.00	18	0.00	1.000
11	1.70	2.90	18	-2.37	.029	0.00	.10	18	-1.00	.331	0.00	0.00	18	0.00	1.000
12	1.00	1.50	18	-.92	.369	0.00	0.00	18	0.00	1.000					
13	.70	1.50	18	-1.60	.134	0.00	0.00	18	0.00	1.000					
14	1.10	2.10	18	-1.50	.150	0.00	0.00	18	0.00	1.000					
15	.80	2.30	18	-2.70	.015	0.00	0.00	18	0.00	1.000					
16	.70	1.70	18	-1.58	.132	0.00	0.00	18	0.00	1.000					
17	.40	1.30	18	-1.89	.086	0.00	0.00	18	0.00	1.000					
18	.10	1.00	18	-2.38	.039	0.00	0.00	18	0.00	1.000					
19	.10	.20	18	-.60	.556										
20	0.00	0.00	18	0.00	1.000										
21	0.00	0.00	18	0.00	1.000										
22	0.00	0.00	18	0.00	1.000										
23	0.00	0.00	18	0.00	1.000										
24	0.00	0.00	18	0.00	1.000										
25	0.00	0.00	18	0.00	1.000										
26	0.00	0.00	18	0.00	1.000										
27	0.00	0.00	18	0.00	1.000										
28	0.00	0.00	18	0.00	1.000										
29	0.00	0.00	18	0.00	1.000										
30	0.00	0.00	18	0.00	1.000										

*Intensity rating on a scale of 0-5.

**The probability of the difference between the group means occurring by chance if no difference existed in the population means; calculated by a t-test of independent means; each group N = 10.

APPENDIX K

GROUP SPECTRAL PROFILES BASED ON INTENSITY RATINGS OF
THE SPECTRAL CHARACTERISTICS OF VOCAL SOUNDS
PRODUCED IN SOLO AND BLEND CONTEXTS

Fig. 22--Group spectral profiles comparing vocal sounds produced in solo context (solid line) and blend context (line with each partial marked with a box figure) for the vowel [ɑ] and the pitch C4 (261 Hz.).

Fig. 23--Group spectral profiles comparing vocal sounds produced in solo context (solid line) and blend context (line with each partial marked with a box figure) for the vowel [a] and the pitch A4 (440 Hz.).

Fig. 24--Group spectral profiles comparing vocal sounds produced in solo context (solid line) and blend context (line with each partial marked with a box figure) for the vowel [a] and the pitch F^5 (698 Hz.).

Fig. 25--Group spectral profiles comparing vocal sounds produced in solo context (solid line) and blend context (line with each partial marked with a box figure) for the vowel [O] and the pitch C⁴ (261 Hz.).

Fig. 26--Group spectral profiles comparing vocal sounds produced in solo context (solid line) and blend context (line with each partial marked with a box figure) for the vowel [O] and the pitch A⁴ (440 Hz.).

Fig. 27--Group spectral profiles comparing vocal sounds produced in solo context (solid line) and blend context (line with each partial marked with a box figure) for the vowel [O] and the pitch F^5 (698 Hz.).

Fig. 28--Group spectral profiles comparing vocal sounds produced in solo context (solid line) and blend context (line with each partial marked with a box figure) for the vowel [u] and the pitch C⁴ (261 Hz.).

Fig. 29--Group spectral profiles comparing vocal sounds produced in solo context (solid line) and blend context (line with each partial marked with a box figure) for the vowel [u] and the pitch A⁴ (440 Hz.).

Fig. 30--Group spectral profiles comparing vocal sounds produced in solo context (solid line) and blend context (line with each partial marked with a box figure) for the vowel [u] and the pitch F5 (698 Hz.).

Fig. 31--Group spectral profiles comparing vocal sounds produced in solo context (solid line) and blend context (line with each partial marked with a box figure) for the vowel [ɛ] and the pitch C⁴ (261 Hz.).

Fig. 32--Group spectral profiles comparing vocal sounds produced in solo context (solid line) and blend context (line with each partial marked with a box figure) for the vowel [ɛ] and the pitch A⁴ (440 Hz.).

Fig. 33--Group spectral profiles comparing vocal sounds produced in solo context (solid line) and blend context (line with each partial marked with a box figure) for the vowel [ɛ] and the pitch F5 (698 Hz.).

Fig. 34--Group spectral profiles comparing vocal sounds produced in solo context (solid line) and blend context (line with each partial marked with a box figure) for the vowel [i] and the pitch C4 (261 Hz.).

Fig. 35--Group spectral profiles comparing vocal sounds produced in solo context (solid line) and blend context (line with each partial marked with a box figure) for the vowel [i] and the pitch A⁴ (440 Hz.).

Fig. 36--Group spectral profiles comparing vocal sounds produced in solo context (solid line) and blend context (line with each partial marked with a box figure) for the vowel [i] and the pitch F^5 (698 Hz.).

APPENDIX L

GROUP SPECTRAL PROFILES BASED ON INTENSITY RATINGS OF THE
SPECTRAL CHARACTERISTICS OF VOCAL SOUNDS IDENTIFIED
AS BLENDING WELL AND BLENDING POORLY
WITH A UNISON ENSEMBLE

Fig. 37--Group spectral profiles comparing vocal sounds identified as blending well (line with each partial marked with a box figure) and blending poorly (solid line) with a unison ensemble for the vowel [a] and the pitch C⁴ (261 Hz.).

Fig. 38--Group spectral profiles comparing vocal sounds identified as blending well (line with each partial marked with a box figure) and blending poorly (solid line) with a unison ensemble for the vowel [a] and the pitch A⁴ (440 Hz.).

Fig. 39--Group spectral profiles comparing vocal sounds identified as blending well (line with each partial marked with a box figure) and blending poorly (solid line) with a unison ensemble for the vowel [A] and the pitch F^5 (698 Hz.).

Fig. 40--Group spectral profiles comparing vocal sounds identified as blending well (line with each partial marked with a box figure) and blending poorly (solid line) with a unison ensemble for the vowel [O] and the pitch C⁴ (261 Hz.).

Fig. 41--Group spectral profiles comparing vocal sounds identified as blending well (line with each partial marked with a box figure) and blending poorly (solid line) with a unison ensemble for the vowel [O] and the pitch A⁴ (440 Hz.).

Fig. 42--Group spectral profiles comparing vocal sounds identified as blending well (line with each partial marked with a box figure) and blending poorly (solid line) with a unison ensemble for the vowel [O] and the pitch F⁵ (698 Hz.).

Fig. 43--Group spectral profiles comparing vocal sounds identified as blending well (line with each partial marked with a box figure) and blending poorly (solid line) with a unison ensemble for the vowel [u] and the pitch C⁴ (261 Hz.).

Fig. 44--Group spectral profiles comparing vocal sounds identified as blending well (line with each partial marked with a box figure) and blending poorly (solid line) with a unison ensemble for the vowel [U] and the pitch A⁴ (440 Hz.).

Fig. 45--Group spectral profiles comparing vocal sounds identified as blending well (line with each partial marked with a box figure) and blending poorly (solid line) with a unison ensemble for the vowel [u] and the pitch F⁵ (698 Hz.).

Fig. 46--Group spectral profiles comparing vocal sounds identified as blending well (line with each partial marked with a box figure) and blending poorly (solid line) with a unison ensemble for the vowel [ɛ] and the pitch C⁴ (261 Hz.).

Fig. 47--Group spectral profiles comparing vocal sounds identified as blending well (line with each partial marked with a box figure) and blending poorly (solid line) with a unison ensemble for the vowel [ɛ] and the pitch A⁴ (440 Hz.).

Fig. 48--Group spectral profiles comparing vocal sounds identified as blending well (line with each partial marked with a box figure) and blending poorly (solid line) with a unison ensemble for the vowel [ɛ] and the pitch F⁵ (698 Hz.).

Fig. 49--Group spectral profiles comparing vocal sounds identified as blending well (line with each partial marked with a box figure) and blending poorly (solid line) with a unison ensemble for the vowel [i] and the pitch C⁴ (261 Hz.).

Fig. 50--Group spectral profiles comparing vocal sounds identified as blending well (line with each partial marked with a box figure) and blending poorly (solid line) with a unison ensemble for the vowel [*l*] and the pitch A⁴ (440 Hz.).

Fig. 51--Group spectral profiles comparing vocal sounds identified as blending well (line with each partial marked with a box figure) and blending poorly (solid line) with a unison ensemble for the vowel [*u*] and the pitch F⁵ (698 Hz.).

APPENDIX M

SONAGRAMS OF THE ENSEMBLE

Fig. 52--The spectral characteristics of the vowel [ɔ], sung at three pitch levels by the ensemble. The sonagrams were prepared from the ensemble tape loops.

Fig. 53--The spectral characteristics of the vowel [O], sung at three pitch levels by the ensemble. The sonagrams were prepared from the ensemble tape loops.

Fig. 54--The spectral characteristics of the vowel [ɯ], sung at three pitch levels by the ensemble. The sonagrams were prepared from the ensemble tape loops.

Fig. 55--The spectral characteristics of the vowel [ɛ], sung at three pitch levels by the ensemble. The sonagrams were prepared from the ensemble tape loops.

Fig. 56--The spectral characteristics of the vowel [i], sung at three pitch levels by the ensemble. The sonagrams were prepared from the ensemble tape loops.

APPENDIX N

SONAGRAMS AND REAL-TIME GRAPHS OF FUNDAMENTAL FREQUENCY
FOR THREE SUBJECTS

Subject No. 24 Vowel [C] Spectra = 0.36 seconds each. Vibrato graphs = 2.0 seconds each.

C⁴ (261 Hz.) Blend Solo Blend A⁴ (440 Hz.) Blend Solo Blend F⁵ (698 Hz.) Solo Blend

Fig. 57--The acoustical characteristics of the vowel [C], sung at three pitch levels by subject number 24.

Subject No. 24 Vowel [O] Spectra = 0.36 seconds each. Vibrato graphs = 2.0 seconds each.

C^4 (261 Hz.) A^4 (440 Hz.) F^5 (698 Hz.)

Solo Blend Solo Blend Solo Blend

Fig. 58--The acoustical characteristics of the vowel [O], sung at three pitch levels by subject number 24.

Subject No. 24 Vowel [ʌ] Spectra = 0.36 seconds each. Vibrato graphs = 2.0 seconds each.

C⁴ (261 Hz.) Blend Solo Blend A⁴ (440 Hz.) Blend Solo Blend F⁵ (698 Hz.) Blend Solo Blend

Fig. 59--The acoustical characteristics of the vowel [ʌ], sung at three pitch levels by subject number 24.

Subject No. 24 Vowel [ɛ] Spectra = 0.36 seconds each. Vibrato graphs = 2.0 seconds each.

C⁴ (261 Hz.) A⁴ (440 Hz.) F⁵ (698 Hz.)

Solo Blend Solo Blend Solo Blend

Fig. 60--The acoustical characteristics of the vowel [ɛ], sung at three pitch levels by subject number 24.

Subject No. 24 Vowel [i] Spectra = 0.36 seconds each. Vibrato graphs = 2.0 seconds each.

C⁴ (261 Hz.) Blend Solo Blend Solo Blend F⁵ (698 Hz.) Solo Blend

Fig. 61--The acoustical characteristics of the vowel [i], sung at three pitch levels by subject number 24.

Subject No. 27 Vowel [A] Spectra = 0.36 seconds each. Vibrato graphs = 2.0 seconds each.

C^4 (261 Hz.)	A^4 (440 Hz.)	F^5 (698 Hz.)
Solo	Blend	Solo
		Blend

Fig. 62--The acoustical characteristics of the vowel [A], sung at three pitch levels by subject number 27.

Subject No. 27 Vowel [O] Spectra = 0.36 seconds each. Vibrato graphs = 2.0 seconds each.

C^4 (261 Hz.)	A^4 (440 Hz.)	F^5 (698 Hz.)
Solo	Solo	Solo
Blend	Blend	Blend

Fig. 63--The acoustical characteristics of the vowel [O], sung at three pitch levels by subject number 27.

Subject No. 27 Vowel [u] Spectra = 0.36 seconds each. Vibrato graphs = 2.0 seconds each.

C⁴ (261 Hz.) A⁴ (440 Hz.) F⁵ (698 Hz.)

Solo Blend Solo Blend Solo Blend

Fig. 64--The acoustical characteristics of the vowel [u], sung at three pitch levels by subject number 27.

Subject No. 27 Vowel [ɛ] Spectra = 0.36 seconds each. Vibrato graphs = 2.0 seconds each.

Fig. 65--The acoustical characteristics of the vowel [ɛ], sung at three pitch levels by subject number 27.

Subject No. 27 Vowel [i] Spectra = 0.36 seconds each. Vibrato graphs = 2.0 seconds each.

c^4 (261 Hz.)	A^4 (440 Hz.)	F^5 (698 Hz.)
Solo	Solo	Solo
Blend	Blend	Blend

Fig. 66--The acoustical characteristics of the vowel [i], sung at three pitch levels by subject number 27.

Subject No. 28 Vowel [a] Spectra = 0.36 seconds each. Vibrato graphs = 2.0 seconds each.

C⁴ (261 Hz.) A⁴ (440 Hz.) F⁵ (698 Hz.)

Solo Blend Solo Blend Solo Blend

Fig. 67--The acoustical characteristics of the vowel [a], sung at three pitch levels by subject number 28.

Subject No. 28 Vowel [O] Spectra = 0.36 seconds each. Vibrato graphs = 2.0 seconds each.

C⁴ (261 Hz.) Blend Solo Blend Solo Blend F⁵ (698 Hz.)

Fig. 68--The acoustical characteristics of the vowel [O], sung at three pitch levels by subject number 28.

Subject No. 28 Vowel [U] Spectra = 0.36 seconds each. Vibrato graphs = 2.0 seconds each.

C^4 (261 Hz.) A^4 (440 Hz.) F^5 (698 Hz.)

Solo Blend Solo Blend Solo Blend

Fig. 69--The acoustical characteristics of the vowel [U], sung at three pitch levels by subject number 28.

Subject No. 28 Vowel [E] Spectra = 0.36 seconds each. Vibrato graphs = 2.0 seconds each.

C⁴ (261 Hz.)

A⁴ (440 Hz.)

F⁵ (698 Hz.)

Solo

Blend

Solo

Blend

Solo

Blend

Fig. 70--The acoustical characteristics of the vowel [E], sung at three pitch levels by subject number 28.

Subject No. 28 Vowel [i̯] Spectra = 0.36 seconds each. Vibrato graphs = 2.0 seconds each.

c⁴ (261 Hz.) A⁴ (440 Hz.) F⁵ (698 Hz.)

Solo Blend Solo Blend Solo Blend

Fig. 71--The acoustical characteristics of the vowel [i̯], sung at three pitch levels by subject number 28.

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