#### Dieter Maurer

## Acoustics of the Vowel

**Preliminaries** 

#### Content

#### Acknowledgements

#### 1 Introduction

#### Part I Prevailing Theory and Empirical References

#### 14 1 Prevailing Theory

- 1.1 General Acoustic Characteristics of Vowel Sounds
- 1.2 Language-Specific Acoustic Characteristics of Vowel Sounds
- 1.3 Speaker Group-Specific Acoustic Characteristics of Vowel Sounds
- 1.4 Phonation Type-Specific Acoustic Characteristics of Vowel Sounds and Limitation to Voiced Oral Sounds
- 1.5 Limitation to Isolated Vowel Sounds
- 1.6 Limitation to Vowel Sounds as Monophthongs with Quasi-Constant Sound Characteristics
- 1.7 Speech Community-Specific Acoustic Characteristics of Vowel Sounds
- 1.8 The Prevailing Theory of Physical Vowel Representation
- 1.9 Formalising Prevailing Theory
- 1.10 Illustration

#### 21 2 Prevailing Empirical References

- 2.1 General References
- 2.2 Empirical Reference for Standard German
- 2.3 Other Statistical References

#### Part II Reflections

#### 32 3 Vowels and Number of Formants

- 3.1 Inconstant Number of Vowel-Specific Relative Spectral Energy Maxima in Sounds of Back Vowels and of /a-a/
- 3.2 Inconstant Correspondence between Vowel-Specific Relative Spectral Energy Maxima and Calculated Vowel-Specific Formant Patterns
- 3.3 Inconstant Number of Vowel-Specific Relative Spectral Energy Maxima and of Calculated Vowel-Specific Formants
- 3.4 Addition: "Spurious" Formants

Content vii

- 3.5 Addition: "Flat" Vowel Spectra
- 3.6 Addition: Inconstant Number of Vowel-Specific Formants in Synthesis

#### 35 4 Vowels and Fundamental Frequency

- 4.1 Fundamental Frequency, First Formant and "Grade" of Vowels
- 4.2 Fundamental Frequency, Spectral Envelope, Formant Pattern and "Grade" of Vowels

#### 38 5 Formant Patterns and Speaker Groups

- 5.1 Fundamental Frequency, Spectral Envelope, Formant Pattern and "Grade" of Vowels Uttered by Children, Women and Men
- 5.2 One Vowel. Different Formant Patterns
- 5.3 Different Vowels, One Formant Pattern
- 5.4 A Gap in the Reasoning
- 5.5 Addition: Formant Patterns of Voiced and Whispered Vowel Sounds

#### 45 6 Terms of Reference, Methods of Formant Estimation

- 6.1 Formant and Sound Spectrum
- 6.2 Speaker Group and Vocal-Tract Size
- 6.3 Formant Analysis and Objectivisation
- 6.4 Formant Analysis, Fundamental Frequency and Speaker Group or Vocal-Tract Size
- 6.5 Addition: Parameter Adjustments in Formant Analysis and Inconsistent References to Vocal-Tract Size
- 6.6 Addition: Spectrum, Formant Pattern, Resynthesis
- 6.7 Addition: Formant Analysis and Objectivity with Regard to Synthesised Vowel Sounds
- 6.8 Addition: Formant Patterns and Resynthesis outside of the Framework of Prevailing Theory

viii Content

#### Part III Experiences and Observations

## 56 7 Unsystematic Correspondence between Vowels, Patterns of Relative Spectral Energy Maxima and Formant Patterns

- 7.1 Inconstant Number of Vowel-Specific Relative Spectral Energy Maxima and Incongruence of Vowel-Specific Formant Patterns
- 7.2 Partial Lack of Manifestation of Vowel-Specific Relative Spectral Energy Maxima
- 7.3 Addition: Resynthesis and Synthesis

## 59 8 Lack of Correspondence between Vowels and Patterns of Relative Spectral Energy Maxima or Formant Patterns

- 8.1 Dependence of Vowel-Specific, Relative Spectral Energy Maxima and Lower Formants≤1.5kHz on Fundamental Frequency
- 8.2 Vowel Perception at Fundamental Frequencies above Statistical Values of the First-Formant Frequency
- 8.3 "Inversions" of Relative Spectral Energy Maxima and Minima and "Inverse" Formant Patterns in Sounds of Individual Vowels
- 8.4 Addition: Whispered Vowel Sounds, Fundamental-Frequency Dependence of Vowel-Specific Spectral Characteristics and "Inversions"
- 8.5 Addition: Resynthesis and Synthesis

# 64 9 Ambiguous Correspondence between Vowels and Patterns of Relative Spectral Energy Maxima or Formant Patterns or Complete Spectral Envelopes

- 9.1 Ambiguous Patterns of Relative Spectral Energy Maxima and Ambiguous Formant Patterns
- 9.2 Ambiguous Spectral Envelopes
- 9.3 Ambiguity and Individual Vowels
- 9.4 Addition: Resynthesis and Synthesis

#### 66 10 Lack of Correspondence between Patterns of Relative Spectral Energy Maxima or Formant Patterns and Speaker Groups or Vocal-Tract Sizes

- 10.1 Similar Patterns of Relative Spectral Maxima and Similar Formant Patterns≤1.5 kHz for Different Speaker Groups or Different Vocal-Tract Sizes
- 10.2 The Dichotomy of the Vowel Spectrum

Content ix

- 10.3 Addition: Whispered Vowel Sounds and Speaker Groups or Vocal-Tract Sizes
- 10.4 Addition: Vowel Imitations by Birds
- 10.5 Addition: Resynthesis and Synthesis

#### 70 11 Lack of Correlation between Methodological Limitations of Formant Determination and Limitations of Vowel Perception

- 11.1 Vowel Perception at Fundamental Frequencies > 350 Hz
- 11.2 Lack of Correspondence between Methodological Problems of Formant Pattern Estimation at Fundamental Frequencies ≤ 350 Hz and Impaired Vowel Perception
- 11.3 Addition: Lack of Methodological Basis of Determining Formant Patterns for Vowel Mimicry by Birds

#### Part IV Falsification

- 74 12 Empirical Falsification despite Methodological Limitations of Determining Patterns of Relative Spectral Envelope Maxima or Formant Patterns
  - 12.1 Lack of Methodological Basis for Verifying Prevailing Theory
  - 12.2 Systematic Divergence of Empirical Findings from Predictions of Prevailing Theory
  - 12.3 Empirical Findings Directly Contradicting Prevailing Theory

#### Part V Commentary

- 78 13 Preliminaries
  - 13.1 Impediments to Adjusting Prevailing Theory
  - 13.2 Prevailing Theory as an Index
  - 13.3 Excursus: Vowel Quality and Harmonic Spectrum
  - 13.4 "Forefield"
  - 13.5 Two Approaches
  - 13.6 Phenomenology
  - 13.7 Theory Building

#### 87 Afterword

x Content

#### **Materials**

М	ate	ria	ls	Pa	ırt	I

- 98 M1 Prevailing Theory
- 102 M2 Prevailing Empirical References

#### Materials Part II

- 106 M3 Vowels and Number of Formants
- 107 M4 Vowels and Fundamental Frequency
- 112 M5 Formant Patterns and Speaker Groups
- 118 M6 Terms of Reference, Methods of Formant Estimation

#### **Materials Part III**

- 128 Note on the Method
- 132 M7 Unsystematic Correspondence between Vowels,
  Patterns of Relative Spectral Energy Maxima
  and Formant Patterns
  - M7.1 Inconstant Number of Vowel-Specific Relative Spectral Energy Maxima and Incongruence of Vowel-Specific Formant Patterns
  - M7.2 Partial Lack of Manifestation of Vowel-Specific Relative Spectral Energy Maxima
- 158 M8 Lack of Correspondence between Vowels and Patterns of Relative Spectral Energy Maxima or Formant Patterns
  - M8.1 Dependence of Vowel-Specific, Relative Spectral Energy Maxima and Lower Formants ≤ 1.5 kHz on Fundamental Frequency
  - M8.2 Vowel Perception at Fundamental Frequencies above Statistical Values of the Respective First Formant Frequency
  - M8.3 "Inversions" of Relative Spectral Energy Maxima and Minima and "Inverse" Formant Patterns in Sounds of Individual Vowels

Content xi

# 187 M9 Ambiguous Correspondence between Vowels and Patterns of Relative Spectral Energy Maxima or Formant Patterns or Complete Spectral Envelopes

- M9.1 Ambiguous Patterns of Relative Spectral Energy Maxima and Ambiguous Formant Patterns
- M9.2 Ambiguous Spectral Envelopes
- M9.3 Ambiguity and Individual Vowels

# 217 M10 Lack of Correspondence between Patterns of Relative Spectral Energy Maxima or Formant Patterns and Age- and Gender-Related Speaker Groups or Vocal-Tract Sizes

- M10.1 Similar Patterns of Relative Spectral Maxima and Similar Formant Patterns≤1.5 kHz for Different Age and Gender-Related Speaker Groups or Vocal-Tract Sizes
- M10.2 The Dichotomy of the Vowel Spectrum
- M10.A Addition: Vowel Imitations by Birds

# 249 M11 Lack of Correlation between Methodological Limitations of Formant Determination and Limitations of Vowel Perception

- M11.1 Vowel Perception at Fundamental Frequencies>350 Hz
- M11.2 Lack of Correspondence between Methodological Problems of Formant Pattern Estimation at Fundamental Frequencies ≤ 350 Hz and Impaired Vowel Perception

#### **Experiments**

### 252 E1 Number of Relative Spectral Energy Maxima and Number of Formants

- E1.1 Sounds of Back Vowels Showing only One Lower Spectral Peak≤1.5 kHz
- E1.2 Sounds of Back Vowels Showing only One Pronounced Lower Formant≤1.5 kHz
- E1.3 Sounds of Single Front Vowels Showing Non-Corresponding F2 and F3
- E1.4 Sounds of Back Vowels Showing No Pronounced Spectral Peak≤1.5 kHz
- E1.5 Sounds of Front Vowels Showing No Pronounced Spectral Peak>2 kHz

xii Content

## 254 E2 Patterns of Relative Spectral Energy Maxima, Formant Patterns and Fundamental Frequency

- E2.1 Sounds of Single Vowels Produced at Different F0 Exhibiting Different Spectral Peaks and Different Calculated Formant Patterns: Part 1, Dependence of Formant Patterns on F0
- E2.2 Sounds of Single Vowels Produced at Different F0
  Exhibiting Different Spectral Peaks and Different
  Calculated Formant Patterns: Part 2, Vowel Intelligibility
  for Sounds at F0>500 Hz
- E2.3 Sounds of Single Vowels Produced at Different F0
  Exhibiting Different Spectral Peaks and Different
  Calculated Formant Patterns: Part 3, Resynthesising
  a Formant Pattern at Different F0
- E2.4 Sounds of Single Back Vowels Produced at Different F0 Exhibiting Inverse Spectral Peaks
- E2.5 Special Note Concerning Inconstant Numerical Relationship between Calculated F0 and Formant Patterns

#### 257 E3 Formant Pattern Ambiguity

- E3.1 Formant Pattern Ambiguity in Natural Vocalisations
- E3.2 Formant Pattern Ambiguity in Model Synthesis

## 258 E4 Patterns of Relative Spectral Energy Maxima, Formant Patterns and Age- and Gender-Related Vocal-Tract Sizes

- E4.1 Comparison of Vowel-Specific Spectral Characteristics of Children, Women and Men Related to Different and Similar F0 of Vocalisations: Part 1, Natural Vocalisations
- E4.2 Comparison of Vowel-Specific Spectral Characteristics of Children, Women and Men Related to Different and Similar F0 of Vocalisations: Part 2, Resynthesis

## 260 E5 Patterns of Relative Spectral Energy Maxima, Formant Patterns and Phonation Types

- E5.1 Whispered Sounds Compared with Voiced Sounds at Different F0 in Utterances of a Single Speaker
- E5.2 Whispered Sounds Compared with Voiced Sounds at Different F0 in Utterances of Speakers of Different Speaker Groups
- E5.3 Sounds of Back Vowels Showing Three Spectral Peaks≤1.5 kHz
- E5.4 Sounds of Front Vowels Showing Two Spectral Peaks≤1.5kHz

Content xiii

#### 262 E6 Patterns of Relative Spectral Energy Maxima, Formant Patterns and Vowel Imitation by Birds

- E6.1 Direct Comparisons of Selected Sounds of Humans and Birds
- E6.2 Resynthesis Relating to "Anomalous" Formant Patterns of Sounds of Birds

#### 263 E7 Anomalous Vowel Spectra

- E7.1 Spectra with Increasing Number of Harmonics Equal in Amplitude ("Flat" Vowel Spectra)
- E7.2 Spectra with Increasing Number of Harmonic Pairs Showing Equal Amplitude Differences ("Ridged" Parts of Vowel Spectra)

#### 264 E8 Aspects of Method

- E8.1 Formant Pattern Estimation Related to Non-Standard Parameters
- E8.2 Formant Pattern Estimation at F0>350Hz
- E8.3 Resynthesis of Sounds at Varying F0 and Subsequent Formant Pattern Estimation
- 268 List of Figures
- 274 List of Tables
- 275 References

xiv Content