

Phonetics and Speech Science

Phonetics is a fundamental building block not just in linguistics but also in fields such as communication disorders. However, introductions to phonetics can often assume a background in linguistics, whilst at the same time overlooking the clinical and scientific aspects of the field. This textbook fills this gap by providing a comprehensive yet accessible overview of phonetics that delves into the fundamental science underlying the production of speech. Written with beginners in mind, it focuses on the anatomy and physiology of speech, while at the same time explaining the very basics of phonetics, such as the phonemes of English, the International Phonetic Alphabet, and phonetic transcription systems. It presents the sounds of speech as elements of linguistic structure and as the result of complex biological mechanics. It explains complicated terminology in a clear, easy-to-understand way, and provides examples from a range of languages, from disorders of speech, and from language learning.

Ian R. A. MacKay is retired Professor of linguistics at the University of Ottawa. He has taught phonetics and speech science for 45 years to students of linguistics, speech–language pathology, and audiology.

Phonetics and Speech Science

Ian R. A. MacKay
University of Ottawa



CAMBRIDGE
UNIVERSITY PRESS

Shaftesbury Road, Cambridge CB2 8EA, United Kingdom

One Liberty Plaza, 20th Floor, New York, NY 10006, USA

477 Williamstown Road, Port Melbourne, VIC 3207, Australia

314–321, 3rd Floor, Plot 3, Splendor Forum, Jasola District Centre,
New Delhi – 110025, India

103 Penang Road, #05–06/07, Visioncrest Commercial, Singapore 238467

Cambridge University Press is part of Cambridge University Press & Assessment, a department of the University of Cambridge.

We share the University's mission to contribute to society through the pursuit of education, learning and research at the highest international levels of excellence.

www.cambridge.org

Information on this title: www.cambridge.org/highereducation/isbn/9781108427869

DOI: 10.1017/9781108604642

© Ian R. A. MacKay 2023

This publication is in copyright. Subject to statutory exception and to the provisions of relevant collective licensing agreements, no reproduction of any part may take place without the written permission of Cambridge University Press & Assessment.

First published 2023

Printed in the United Kingdom by TJ Books Limited, Padstow, Cornwall 2023

A catalogue record for this publication is available from the British Library.

A Cataloging-in-Publication data record for this book is available from the Library of Congress.

ISBN 978-1-108-42786-9 Hardback

ISBN 978-1-108-45203-8 Paperback

Additional resources for this publication at www.cambridge.org/MacKay

With few exceptions, illustrations were created by Pascale Cherry.

Cambridge University Press & Assessment has no responsibility for the persistence or accuracy of URLs for external or third-party internet websites referred to in this publication and does not guarantee that any content on such websites is, or will remain, accurate or appropriate.

For JoDo, with thanks for everything

Brief Contents

List of Figures	<i>page</i> xii
List of Tables	xvii
Acknowledgments	xviii
1 Phonetics and Language	1
2 Phonetic Transcription	27
3 Anatomy and Physiology of Speech	45
4 Air Pressure and Aerodynamics	81
5 Consonants	100
6 Vowels	143
7 Sounds of North American English	176
8 Voice, Phonation, and Nasality	186
9 Airstream Mechanisms: Clicks, Implosives, Ejectives, Esophageal Speech	211
10 Speech Dynamics	230
11 Suprasegmentals	273
12 Acoustics	311
13 Interlocutors: Talkers and Hearers	359
Glossary	399
References	428
Index	431

Contents

List of Figures	<i>page</i> xii
List of Tables	xvii
Acknowledgments	xviii
1 Phonetics and Language	1
1.1 Phonetics	1
1.2 Use of typography, symbols, and punctuation	2
1.3 Notes on terminology	4
1.4 Human language	7
1.5 Using the book	12
1.6 Phonetics and phonology	13
1.7 Same phonetic variable, different significance	16
1.8 Kinds of information in speech	18
1.9 A single speech sound	22
1.10 Cautions	23
1.11 Vocabulary	25
2 Phonetic Transcription	27
2.1 Phonetic transcription: history and principles	27
2.2 Why are there differences among experts' transcriptions?	31
2.3 A few notions of typography relevant to transcription and the IPA	35
2.4 Technical matters related to the IPA	40
2.5 Vocabulary	44
3 Anatomy and Physiology of Speech	45
3.1 Anatomy and physiology	45
3.2 The supraglottal organs	48
3.3 The velopharyngeal passage/port (VPP)	56
3.4 The larynx	57
3.5 Phonation	60
3.6 Respiration	61
3.7 Muscles and muscle names	66
3.8 A selection of important muscles and gestures in speech articulation	71
3.9 Vocabulary	79

4	Air Pressure and Aerodynamics	81
4.1	Speech production requires a movement of air	81
4.2	Air fills all spaces	81
4.3	Air pressure	82
4.4	Air pressure equalizes itself	86
4.5	Airflow from higher to lower pressure	88
4.6	Local air pressure disturbances in the production of speech	91
4.7	Bernoulli principle	96
4.8	Vocal fold vibration	97
4.9	Vocabulary	99
5	Consonants	100
5.1	Consonants	100
5.2	Articulation, terms, and consonant naming conventions	101
5.3	Principal places of consonant articulation (PoA)	104
5.4	Types of movement in consonant articulation	107
5.5	The International Phonetic Alphabet	109
5.6	Manners of articulation of consonants	112
5.7	Plosives	113
5.8	Nasals	119
5.9	Fricatives	121
5.10	Affricates	128
5.11	Approximants	129
5.12	Flaps	134
5.13	Trills	135
5.14	Secondary articulation and double articulation	136
5.15	Fortis versus lenis and other differences	138
5.16	Other types of consonants	138
5.17	Diacritics introduced in this chapter	139
5.18	Consonant table as introduced in this chapter	140
5.19	Vocabulary	142
6	Vowels	143
6.1	Vowels and consonants	143
6.2	IPA vowel table	145
6.3	Cardinal vowels and the vowel quadrangle	145
6.4	Where are front and back? What is high or low?	152
6.5	Non-cardinal vowels	154
6.6	Rounding	157
6.7	Tense and lax; ATR	158
6.8	Nasalization; nasalized vowels; nasal vowels	159
6.9	Vowel duration (“length”)	161

	Contents	ix
6.10 Diphthongs	163	
6.11 Diphthongized vowels	166	
6.12 Terminology	168	
6.13 Vocoids and syllabicity	169	
6.14 Glides and approximants	170	
6.15 On-glides, off-glides, and transitional glides	172	
6.16 Diacritics introduced in this chapter	173	
6.17 Vocabulary	174	
7 Sounds of North American English	176	
7.1 The sounds of General American English	176	
7.2 Consonants and vowels	177	
7.3 Sound inventory of General American English	178	
7.4 Consonants	179	
7.5 Approximants	180	
7.6 American English has a non-rhotic flap	182	
7.7 The relationship between glides and vowels	182	
7.8 Vowels	183	
7.9 Word stress	184	
8 Voice, Phonation, and Nasality	186	
8.1 Voice and phonation	186	
8.2 The glottis	187	
8.3 Production of voice; voicing	188	
8.4 Voice onset time	192	
8.5 Voice production in greater detail	195	
8.6 Modes of vocal fold vibration: types of voice	203	
8.7 Whisper	205	
8.8 Nasality	206	
8.9 IPA symbols introduced or mentioned in this chapter	209	
8.10 Vocabulary	209	
9 Airstream Mechanisms: Clicks, Implosives, Ejectives, Esophageal Speech	211	
9.1 Different types of airstream	211	
9.2 The pulmonic airstream mechanism	212	
9.3 The glottalic airstream mechanism: ejectives and implosives	214	
9.4 The ingressive velaric/lingual/oral airstream mechanism: clicks	217	
9.5 Laryngectomees	220	
9.6 Buccal speech	222	
9.7 The esophageal airstream mechanism	223	

x Contents

9.8	Table of consonants introduced in this chapter	226
9.9	Airstream mechanism summary table	227
9.10	IPA symbols	229
9.11	Vocabulary	229
10	Speech Dynamics	230
10.1	Introduction	230
10.2	The nature of accommodation	232
10.3	The causes of accommodation	237
10.4	Hyperspeech and hypospeech (H&H Theory)	240
10.5	Do segments exist?	242
10.6	Types of accommodation	247
10.7	Variants of some English segments	249
10.8	Primary and secondary articulations	255
10.9	Noncontiguous (distant) accommodation	257
10.10	Metaphony (distant vowel accommodation)	259
10.11	Stress and accommodation	264
10.12	Sandhi	264
10.13	Other combinatory phenomena	266
10.14	Speech errors	270
10.15	IPA symbols introduced in this chapter	271
10.16	Vocabulary	271
11	Suprasegmentals	273
11.1	Introduction	273
11.2	Types of suprasegmental elements	274
11.3	Prominence	275
11.4	Stress	277
11.5	How languages use stress	286
11.6	English word stress	289
11.7	Phrasal stress	293
11.8	Emphasis	293
11.9	Contrastive emphasis	294
11.10	Weak forms	296
11.11	Intonation	297
11.12	Timing	300
11.13	Tone	303
11.14	Pitch accent	305
11.15	Voice quality	306
11.16	Articulatory setting	307
11.17	Summary table	308
11.18	IPA symbols introduced in this chapter	309
11.19	Vocabulary	309

12 Acoustics	311
12.1 Acoustics – sound	311
12.2 Wave motion	312
12.3 Dimensions of waves	313
12.4 Periodicity	317
12.5 Wave motion of sound	318
12.6 Perceptual dimensions of sound waves	324
12.7 Harmonics	329
12.8 Spectra and spectrograms	331
12.9 Addition of waves	333
12.10 Standing waves	338
12.11 Resonance	341
12.12 Acoustic principles applied to the vocal tract: vowels	347
12.13 Acoustics of vowels	350
12.14 Acoustics of consonants	354
12.15 Vocabulary	358
13 Interlocutors: Talkers and Hearers	359
13.1 Interlocutors, talkers, and hearers	359
13.2 Speech versus written text	360
13.3 Rate of information transfer	365
13.4 Speech perception	367
13.5 The ear	377
13.6 Hearing	393
13.7 Effects of hearing impairment on speech production	395
13.8 Vocabulary	397
Glossary	399
References	428
Index	431

Figures

2.1.	Serifs	<i>page 38</i>
3.1 A.	The three body planes shown on drawings of the human body	47
	B. The planes are shown as cross-sections of the head. Image credit: mr.suphachai praserdumrongchai / iStock.	47
3.2.	A cross-section (midsagittal view) of the head	49
3.3.	Divisions of the tongue surface	50
3.4.	The palate and surrounding structures	53
3.5.	The uvula	53
3.6.	The divisions of the pharynx, and oral and nasal cavities	54
3.7.	The airway crosses the passageway for food and liquid	55
3.8.	Velopharyngeal port, open (A) and closed (B). Source: Cummings (2013).	56
3.9.	The larynx and the laryngeal cartilages	59
3.10.	The conus elasticus and the vocal folds as seen from above	59
3.11.	The vocal folds in schematic cross-section	60
3.12.	The thorax in inspiration and expiration	63
3.13.	The intercostal muscles in inspiration and expiration	64
3.14.	Muscle fibers	68
3.15.	Muscles: two important facts	69
3.16.	Muscles of the velum and upper pharynx	71
3.17.	Posterior view of muscles of the velum	72
3.18.	Action of intrinsic tongue muscles	73
3.19 A.	Tip-raising and arching demonstrated with a piece of folded paper	74
	B. Intrinsic tongue muscles	74
3.20.	Changing the shape of the tongue in coronal cross-section	75
3.21.	Lowering the tongue body	76
3.22.	Raising the back of the tongue	77
3.23.	Muscles of facial expression in speech articulation	78
3.24.	Some mandibular muscles	79
4.1.	Air pressure is exerted in all directions	82
4.2.	All air passageways are full of air at all times	82
4.3.	Inhaling as airflow from high pressure to low pressure	92
4.4.	Impounding air for plosives	94

	List of Figures	xiii
4.5. The Bernoulli principle	96	
5.1. Places of articulation	105	
5.2. The International Phonetic Alphabet (consonants). Available under a Creative Commons Attribution-Sharealike 3.0 Unported License. Copyright © 2020 International Phonetic Association	111	
5.3. The International Phonetic Alphabet (non-pulmonic consonants). Available under a Creative Commons Attribution-Sharealike 3.0 Unported License. Copyright © 2020 International Phonetic Association.	112	
5.4. The International Phonetic Alphabet (other [consonant] symbols). Available under a Creative Commons Attribution-Sharealike 3.0 Unported License. Copyright © 2020 International Phonetic Association.	112	
5.5. Tongue seal along the molars	116	
5.6. An ultrasonic image of an American English bunched [ɹ]. Source: www.youtube.com/watch?v=-bKOot2WHhI . Copyright © Queen Margaret University, Edinburgh, Scotland	133	
5.7. An ultrasonic image of a retroflexed [ɻ]. Source: www.youtube.com/watch?v=-bKOot2WHhI . Copyright © Queen Margaret University, Edinburgh, Scotland.	134	
6.1. The International Phonetic Alphabet vowel table. Image modified from IPA Chart, www.internationalphoneticassociation.org/content/full-ipa-chart . Available under a Creative Commons Attribution-Sharealike 3.0 Unported License. Copyright © 2015 International Phonetic Association.	145	
6.2. Primary cardinal vowels. Image modified from IPA Chart, www.internationalphoneticassociation.org/content/full-ipa-chart . Available under a Creative Commons Attribution-Sharealike 3.0 Unported License. Copyright © 2015 International Phonetic Association.	146	
Sidebar 6.2. Image modified from IPA Chart, www.internationalphoneticassociation.org/content/full-ipa-chart . Available under a Creative Commons Attribution-Sharealike 3.0 Unported License. Copyright © 2015 International Phonetic Association.	149	
6.3. Secondary cardinal vowels. Image modified from IPA Chart, www.internationalphoneticassociation.org/content/full-ipa-chart . Available under a Creative Commons Attribution-Sharealike 3.0 Unported License. Copyright © 2015 International Phonetic Association.	150	

6.4.	Vowel quadrangle in place	154
6.5.	Inaccurate vowel quadrangles as seen in various reference works	155
6.6A.	The IPA vowel chart, repeated from Figure 6.1. Image modified from IPA Chart, www.internationalphoneticassociation.org/content/full-ipa-chart . Available under a Creative Commons Attribution-Sharealike 3.0 Unported License. Copyright © 2015 International Phonetic Association.	155
B.	All of the non-cardinal vowels for which there are special IPA symbols. Image modified from IPA Chart, www.internationalphoneticassociation.org/content/full-ipa-chart . Available under a Creative Commons Attribution-Sharealike 3.0 Unported License. Copyright © 2015 International Phonetic Association.	155
6.7.	Oral and nasalized vowels, [ɛ] and [ẽ]	160
6.8.	The diphthong /ai/	164
8.1.	Positions of the arytenoid cartilages and consequent positions of the vocal folds and size and shape of the glottis	188
8.2.	The glottal cycle. Reprinted from www.scielo.br/scielo under a Creative Commons Attribution Licence.	190
8.3.	Voice onset time	194
8.4.	Fiber-optic viewing of the vocal folds	196
8.5.	The vocal folds in cross-section	196
8.6.	Up-and-down movement in vocal fold vibration	199
8.7.	The vocal folds do <i>not</i> move apart and together this way	199
8.8.	Vocal fold vibration in cross-section	200
8.9.	A mechanical 2-mass model	201
8.10.	Development of the palate	208
9.1.	Pulmonic egressive airstream mechanism	212
9.2.	Glottalic egressive airstream mechanism (ejectives or glottalized consonants)	215
9.3.	Velaric ingressive airstream mechanism (clicks)	218
9.4.	Respiration in a laryngectomy	221
9.5.	Laryngectomy's airway and a tracheoesophageal shunt for producing esophageal speech	226
10.1.	Accommodation: coarticulation – /iki/, /uku/, /aka/	233
10.2.	Accommodation: coarticulation /obo/, /omo/	234
10.3.	Accommodation: coarticulation /ibi/, /obo/	235
10.4.	Bamab and bambab	246
11.1.	The vowel reduction continuum	281

11.2. A closer look at the vowel reduction continuum	281
11.3. Spectrograms of the Swedish word <i>anden</i> with Swedish Tone 1 and Tone 2	306
12.1. A surface wave on water	312
12.2. The cycle of a wave	313
12.3. Amplitude and wavelength	315
12.4A. A periodic wave	318
B. An aperiodic wave	318
12.5. Wave motion on water, in a Slinky, and through the air	320
12.6. Passage of a single cycle of a wave	321
12.7. Variations in air pressure and molecular displacement	322
12.8. Sound waves moving away from a point source	323
12.9. Phase	327
12.10. Spectra of the glottal source of the voice	330
12.11. A spectrum of sound	332
12.12. Relationship between spectra and a spectrogram	334
12.13. A spectrogram of the phrase “two, three, four”	334
12.14. The operation of Fourier’s Theorem	336
12.15. Some complex periodic waves	337
12.16. A reflected wave	339
12.17. A standing wave	340
12.18. A standing wave	342
12.19. Resonance	343
12.20. Tuning	344
12.21. Tuning	344
12.22. Resonance in open and closed resonators	346
12.23. Spectrogram of a soft-drink (soda) bottle resonator. Source: sound file https://bigsoundbank.com/detail-1939-bottle-blow-1.html	347
12.24. The source–filter theory of vowel production	350
12.25. A two-resonator model of speech	351
12.26. Spectrograms of the vowels /i u ɑ æ/ with the formants highlighted	352
12.27. Stylized spectrograms showing formant transitions for plosives of each place of articulation followed by the vowel [ɑ]. Used by permission of the American Institute of Physics.	354
12.28. Spectrograms of synthetically produced syllables, showing second formant transitions that produce the voiced plosives before various vowels. From Delattre, Liberman, and Cooper (1955). Used by permission of the American Institute of Physics.	355

xvi **List of Figures**

12.29.	The loci of the formant transitions of the alveolar plosives /d/ and /t/	356
12.30.	Spectrograms of voiceless fricatives	357
12.31.	Spectrograms of several approximants	357
12.32.	Spectrograms of several nasal consonants	357
13.1.	Segmentation of speech	369
13.2.	The ear	378
13.3.	Underwater swimmer hears the metal ladder vibrating underwater, but does not hear a voice generated above the water	380
13.4.	Impedance mismatch	381
13.5.	A magnifying glass captures the sun’s energy over the entire glass surface, and concentrates it on one small spot	382
13.6.	The lever permits the trading of force for distance	382
13.7.	The cochlea shown “unrolled”	384
13.8.	The cochlea shown with the scalas visible	385
13.9.	Scala media, showing organ of Corti and associated structures	387
13.10.	Basilar membrane, organ of Corti, and the tectorial membrane	388
13.11.	The volley principle. Source: https://commons.wikimedia.org/wiki/File:Volley_Principle_of_Hearing.png	390
13.12.	Place encoding on the organ of Corti	391
13.13.	Audiogram	394

Tables

1.1.	Use of special marks in the text	<i>page 4</i>
1.2.	Traunmüller's information sources in speech	18
2.1.	Lower-case letters, ascenders and descenders	37
2.2.	Roman versus italic	38
3.1.	Anatomical divisions of the tongue surface used for naming places of articulation	50
4.1.	Normal air pressure at sea level: standard units	84
5.1.	Secondary articulations	137
5.2.	The consonant table as described in this chapter	141
6.1.	Terms in the IPA vowel chart	145
6.2.	Pronunciations close to the primary cardinal vowels	148
6.3.	Pronunciations close to the secondary cardinal vowels	151
8.1.	Fundamental frequencies for different talkers and a singer	191
8.2.	Contrast between murmured and modal plosives	204
8.3.	Creaky voice in Danish	205
11.1.	English vowels under primary, secondary, and tertiary stress	283
11.2.	Tones of the Common Tongue (Mandarin) dialect of Chinese	304
12.1.	Speed of propagation of sound in air at sea level	317
12.2.	Wavelengths in air of some example frequencies	326
12.3.	Formant and fundamental frequencies of the vowel /i/ in American English	348
12.4.	Formant and fundamental frequencies of the vowel /u/ in American English	349
12.5.	Frequencies of F1, F2, and F3 in vowels of American English	353

Acknowledgments

Any author of a textbook such as this must recognize the many people who have assisted in its writing and production. I wish, in particular, to thank Senior Commissioning Editor Helen Barton of Cambridge University Press for her support in accepting and assisting the creation of the book. Her ongoing patience and backing of the project have been instrumental in its writing. I likewise wish to thank Editorial Assistant, Isabel Collins, for assistance along the way.

Family is unavoidably affected when one writes a book; I owe a great deal for the unreserved support and patience I have been accorded.

A number of individuals have helped in myriad ways. Natalia Fullana, Ph.D., of the University of Barcelona (Universitat de Barcelona) read early chapters and made many helpful suggestions. Tom Goldman, Ph.D., provided helpful feedback on portions of the final chapter related to hearing.

It would be impossible to fully express the depth of my gratitude to the illustrator, Pascale Cherry, for her wonderful drawings. Pascale showed great dedication to the project, and she shows such talent for creating clear drawings, whether anatomical or graphical, that are informative and easily interpretable.

Nicola Chapman headed the production team at Cambridge University Press, and I am most grateful to her for performing this complex task with great professionalism and flexibility. Leigh Muller was copy-editor, and I am most grateful to her for her excellent suggestions for improvements, and for catching mistakes.

I would like to thank a number of anonymous individuals. One group of three reviewed the prospectus and read sample chapters. I am grateful for their encouragement. Later, the nearly completed manuscript was read in full by two individuals who submitted detailed commentary. I wish to thank them for their positive comments, as well as for their many helpful suggestions and criticisms, all of which were carefully considered, and most of which were incorporated.

Of course, any academic owes so much to the great number of scholars who built the knowledge base of the discipline. I want to thank them as well as my own professors and colleagues.

A university teacher gains from the wisdom – and struggles – of one’s students. Teaching phonetics for many years has influenced how many of the subjects within the book are presented, based on what made the best sense to my students. Several classes of mine used early versions of some of these chapters as their assigned reading, and their feedback was invaluable in improving those chapters.