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Introduction

Rachael-Anne Knight and Jane Setter

How is speech produced, perceived and processed? How is it used by individuals and speech communities, and how does it change over time? How is speech learned, by first- and second-language speakers, and how does it present when it is disordered? These questions, alongside many more, are of interest to researchers in the broad field of phonetics. Phonetics has a long history, dating at least from writing systems in the ancient world, and has continually evolved as a discipline in response to new theories, methods and technologies (see, for example, Heselwood et al., 2013, for a full historical overview). Today, the field is broad, and interdisciplinary, as shown by the coverage of phonetics journals and conferences, and the chapters in this handbook.

The *Cambridge Handbook of Phonetics* is intended to provide a comprehensive guide to contemporary issues in phonetics, thus it provides coverage of the broad and increasingly multidisciplinary field of phonetics. It will furnish postgraduate students and academic staff with state-of-the-art knowledge in the many sub-disciplines of the field, and suggest how this knowledge can best be used for teaching the next generation of phoneticians. Our aim is to take a global perspective, drawing on a wide range of languages, theories and methodologies, showcasing the individual sub-disciplines, but also highlighting the ways these sub-disciplines interact and their common concerns.

Structure of the Handbook

The *Handbook* is divided into broad sub-disciplines of phonetics, broadly reflecting the speech chain. The first two sections cover articulatory phonetics, focusing on segmental and prosodic production, respectively. The next section is broadly focused on acoustic phonetics and the measurement of speech. The fourth covers audition and perception, while the final

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section considers the application of phonetics to a number of other areas that are disciplines in their own right, such as developmental language and clinical linguistics. The structure is not intended to suggest that the basic distinctions inherent in the volume's organisation, such as between segments and prosody, or between production and perception, are uncontested or without complication. Instead, the aim is to enable readers to both understand the structure of the discipline and focus their reading in a particular area, in order to more fully engage with these wider theoretical discussions. We return to points concerning the nature and structure of the discipline towards the end of the introduction.

Our aim in each chapter is to provide a thorough overview of the subdiscipline. Each chapter begins with a historical overview, to situate the discipline within its historical setting and within the broader discipline of phonetics. Authors then describe critical issues in their field, covering relevant terminology and those facets of the field most important to its further understanding. Sections on recent research provide readers with the most up-to-date areas of focus, before future directions are suggested. A section in each chapter also describes best practice in teaching and learning to ensure that academics are best equipped to facilitate student learning, and to develop an integrated approach to teaching and research. This becomes ever more important given the growth of interest in teaching excellence both in the UK and globally.

Chapter Overview

The first section focuses on segmental production, with Wrench and Beck beginning in Chapter 1 with the neurophysiology of articulatory structures. They review the components of the speech apparatus, including the coordinating neurophysiology, before considering the role of digital biomechanical modelling. Chapters 2 and 3 consider the production of vowels and consonants, respectively. In Chapter 2, Weckwerth describes traditional approaches to conceptualising the vowel space, based on tongue height and advancement, and lip rounding, as well as more modern approaches including the tongue root and pharynx, issues in vowel transcription, and the roles of variability and gradience. In Chapter 3 Proctor briefly describes the categorisation of consonants in terms of voice, place, manner and airstream, before moving on to describe phonetic parameters individually and explore the nature of their coordination and the dynamic properties of the articulators.

Chapters 4 and 5 consider aspects relating to the combination of segments, namely coarticulation and connected speech processes. Iskarous and Mooshammer discuss theoretical and experimental approaches to coarticulation in Chapter 4, considering one- (exemplar) and two-level theories, both temporal and mechanical, and current models. Warner in Chapter 5 considers the phenomena that occur in units of speech larger

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than the single word, including those that occur at word boundaries regardless of speech style and those that are restricted to conversational speech, to answer the question: How is phonetics different in connected speech than in isolated words?

Section II considers prosodic production, beginning with Cantarutti and Szczepek Reed's discussion of stress and rhythm in Chapter 6. They discuss the phonetic correlates of stress, the domains over which stress and accent operate and the representation of stress. In relation to rhythm they summarise the rhythm class and isochrony debate, considering rhythm as a perceptual phenomenon, and as an alternation of strong and weak elements. In Chapter 7, Lee and Mok consider tone, including its acoustic correlates, tone variation in context and the methods used in research on tone production, including articulatory methodologies.

Warren and Calhoun in Chapter 8 consider intonation in the tone-based Autosegmental-Metrical framework, comparing this with the tune-based British tradition. They cover the phonetic variables of intonation, how intonation relates to and signals linguistic structures, and how intonation varies between and within speakers and changes over time. In Chapter 9, Esling and Moisik take a broad view of voice quality (VQ), considering the larynx as an articulator with multiple roles as a source. They consider the role of the larynx in the modelling of VQ and the use of imaging methodologies to investigate VQ.

Section III moves to look more explicitly at measuring speech, thus complementing and extending the descriptions of measurement techniques touched upon in other sections, beginning with the acoustic measurement of segments, covering vowels and consonants in Chapters 10 and 11, respectively. In Chapter 10, Yang covers the acoustic measurement of vowels, including formants, duration, f_0 and intensity to ensure valid and reliable measurements. Figueroa and Kim consider similar issues for the measurement of consonants in Chapter 11, which is organised by manner of articulation, considering what, where and how to measure.

The next two chapters consider the measurement of prosodic phenomena, rhythm and f_0, respectively. Arvaniti in Chapter 12 considers production and perception approaches to the measurement of rhythm, further extending the rhythm class debate introduced in Chapter 6, addressing theoretical and practical issues, and proposing the separation of rhythm and timing. In Chapter 13, Hirst and De Looze address issues of measuring fundamental frequency and pitch in relation to detection, using time- and frequency-domain approaches, modelling and acoustic scales, with a focus on obtaining accurate estimates of f_0.

In Chapter 14, Lin focuses on observing and measuring articulation, describing the most common methods in research. A range of techniques are surveyed in relation to their coverage of the vocal tract, their temporal resolution and their portability, and the advantages and drawbacks of each are discussed. Chapter 15 by Patel, Meltzner and Toman describes speech

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synthesis, including the representation of linguistic and acoustic information, concatenation of the building blocks of speech, and statistical methods for learning the patterns of speech. They focus on approaches to the naturalness of spoken content and the personalisation of text-to-speech systems

Section IV focuses on audition and perception and begins with Wong, Antoniou and Wong's discussion of the neurological foundations of phonetic sciences, in Chapter 16. They include an overview of the hearing brain and a review of brain imaging methods, with a focus on bottom-up perspectives, showcasing network approaches which focus on the importance of interaction between brain regions. In Chapter 17, Sumner and Kim provide an overview of psycholinguistic aspects of phonetics, considering phonetic variation, spoken word recognition, memory and sociolinguistics. They describe tensions between experimental control and signal integrity, and the crucial role of memory in spoken language processing.

In Chapter 18, Reinisch and Mitterer describe how eye-tracking is used to investigate spoken language processing in real time. They focus on classic issues in phonetics that eye-tracking can address, such as how word recognition is affected by connected speech processes and the role of intonation in sentence comprehension. Siniscalchi and Lee in Chapter 19 describe automatic speech recognition by machines, covering pattern matching, channel decoding and the Hidden Markov Model for modelling speech units, and compare top-down approaches with those using bottom-up integration.

Section V builds on the previous chapters to survey the applications of phonetics in other fields and disciplines. In Chapter 20, Whitworth joins the editors to consider the integration of pedagogy and phonetics, focusing on key issues in learning and teaching phonetics to students, drawing on subject knowledge alongside wider educational debates and research. In Chapter 21, Setter and Makino approach the integration of phonetics and pedagogy from a different angle, reviewing the use of phonetics in pronunciation teaching, including pronunciation models or accents, choosing which aspects of phonetics to teach to L2 learners and the crucial role of suprasegmentals.

In Chapter 22, Drager and Kettig review the research questions and methods of sociophonetics, describing methods in production, perception and analysis in variationist and cognitive sociophonetics, while discussing the issues critical to the field's expansion. Rose, McAllister and Inkelas concentrate on developmental phonetics in Chapter 23, surveying the interaction between speech production and other parts of a child's linguistic system, and providing an overview of traditional and recent methods in the field.

In Chapter 24, Moreland focuses on the relationship between phonetics and speech and language therapy, considering the phonetics/phonology interface in relation to clinical work, how transcription is applied clinically at different levels, and the role of instrumental analysis. Hudson, McDougall and Hughes describe the application of phonetics in forensic settings in Chapter 25, and the importance of fine phonetic detail to

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speaker discrimination. They consider analysis by ear, from experts and naïve listeners, acoustic analysis and automatic analysis of the speech signal, and how to arrive at and communicate conclusions.

In Chapter 26, Ogden discusses the phonetics of talk in interaction, considering all aspects of speech production and describing the use of techniques from conversation analysis to understand the phonetic features of interaction, with a focus on turn-taking. Finally, in Chapter 27, Kennedy surveys the phonetics/phonology interface considering evidence from experimental phonology and linguistic phonetics research relating to the interface of continuous phonetic dimensions and abstract phonological categories in segments and suprasegmentals.

Final Remarks

While each of the chapters addresses the particular concerns of that area or sub-discipline, there are two sections that demonstrate common and core concerns and unified directions within the field of phonetics. The sections on teaching and learning practices show a number of commonalities aligned with current concerns in pedagogy and higher education. As examples, chapters point to the importance of active learning, and involving students in productive tasks, rather than relying solely on didactic methods. They stress the importance of showing the application of phonetic concepts, of allowing students to construct their own knowledge, and of students working in communities of practice to build their own understanding of complex topics. All these concerns address multiple dimensions of the United Kingdom Professional Standards Framework (HEA, 2011) for teaching and supporting learning in higher education, which is now being adapted internationally. A mapping of how this framework can be utilised in phonetics teaching accompanies the phonetics pedagogy chapter, and is available on the website accompanying this volume www.cambridge.org/CambridgeHandbookPhonetics.

The future directions sections also make a number of overlapping suggestions and predictions for the development of the field of phonetics. For example, many of our chapters discuss expanding the field by taking advantage of recent advances in large-scale corpora and big data and by continuing to broaden our focus by turning our attention to lesser-documented languages. This increase in breadth is complemented by a predicted increase in depth, including the importance of variability and individual differences. Many of these streams of future work are enabled by changes in technology, and by increased automation of analysis and measurement. The importance of working across sub-disciplines is highlighted, looking at the integration of different parts of communicative systems, as is the importance of working outside of phonetics, by collaborating with other professionals and the sharing of data and methods, both within and outside of phonetics.

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The number of comments about working across fields reflects our claim at the start of this introduction that phonetics is an increasingly broad and interdisciplinary field. Schommer-Aikins et al. (2003) state that disciplines differ from one another in terms of their areas of interest, research methods and epistemology. Interestingly, the chapters in this volume reflect differences in each of these areas, apart from the most general premise that phonetics is the science of speech. Some insights into the current status of phonetics as a discipline can be gained through the work of Cohen and Lloyd (2014), who discuss the development of scientific disciplines through the lens of evolutionary theory. While they do not cover phonetics, they note many changes in disciplines that are relevant to our own. For example, they note that disciplines can be subject to mutation, speciation, parallel evolution and extinction. Ashby (2016) presents worrying trends in relation to the number of courses taught at universities, particularly in relation to general phonetics, due partly to the cost associated with small-group teaching. While this possible precursor to extinction, in the evolutionary framework, does not make for positive reading, there is hope. Ashby goes on to discuss the importance of the applications of phonetics and the integration of technological solutions into teaching. The same opportunities can be said to exist for the discipline as a whole, resulting in heterosis, the integration of ideas from beyond a disciplinary silo, which is viewed as resulting in superior outcomes (Cohen & Lloyd, 2014, p. 200).

On this basis, we would argue that phonetics remains an integrated and thriving discipline. As Ohala pointed out in 1994, the major conferences and journals of the field were inherently broad in their coverage. The same is true twenty-five years later, with the 2019 International Congress of Phonetics Sciences, for example, covering thirty sub-disciplines as scientific areas. Stichweh (2001, p. 13728) notes that 'Scientific communities rest on the intensification of interaction, shared expertise, a certain commonality of values, and the orientation of community members towards problem constellations constitutive of the respective discipline.' This can be said to be true of phonetics and echoes Kohler's (1995) assertion that phonetics is a language science in its own right. We hope that this volume can encourage all interested parties, researchers, teachers and students, to continue to pursue the discipline in any, or many, of its branches, and to ensure a positive and thriving evolution of phonetics as a discipline.

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Section I

Segmental Production

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1

Physiological Foundations

Alan Wrench and Janet Beck

1.1 Introduction

An understanding of biological structures and functions is important for anyone wishing to explore inter-speaker variation in phonetic output, to understand coarticulation, to interpret ultrasound/magnetic resonance imaging (MRI)/X-ray images or to understand speech production associated with atypical anatomy or physiology (e.g. in cleft lip and palate). Descriptions of speech anatomy and physiology often give the impression that there is a 'standard' structure, shared by all. In fact, the extent of between-speaker variation in size and shape of soft and hard tissues is considerable, and it is testament to the flexibility of the articulatory structures that, despite these differences, similar phonetic targets can be reached by morphologically dissimilar speakers. There is evidence, however, that morphological bias within a population may correlate with phonetic inventory. Recent research shows that communities that include clicks in their language have a high proportion of the population with palate shapes that seem to facilitate their production (Dediu et al., 2017).

1.2 Historical Overview

The neuroanatomical and neurophysiological underpinnings of speech are still only partially understood. Historically, the neurophysiological control of speech has been treated somewhat as a black box, and theoreticians have proposed various models to explain the serial and parallel processes that are required to translate a communicative concept into physical realisation as speech (e.g. Levelt, 1989). With the advent of optical, magnetic and electrical instrumentation to measure correlates of cellular activity and with chemical tracing of neurotransmitters, efforts are being made to map elements of these models to different regions of the brain or

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to develop new models based on physiology (e.g. Guenther, 2016). Similarly, despite many descriptions of anatomical detail of the vocal tract that date back to Galen in the second century and beyond, the anatomy of the vocal tract, particularly from a functional perspective, remains an active area of research (as indicated in Section 1.4).

1.3 Critical Issues

This section reflects the task of speech production, starting with an overview of the neurophysiology that coordinates movement of the speech apparatus, followed by an overview of each component of that apparatus starting with the respiratory system, then the larynx, the pharynx, the velopharyngeal and oral articulatory systems, the jaw and the lips. Each part of the system is described in turn, but it should be noted that anatomical and neural interconnectivity is such that muscular adjustments in any part of the vocal apparatus are likely to affect other parts of the speech production system.

1.3.1 Central Nervous System (CNS): Cortical

The primary motor cortex forms part of a distributed network of cortical motor areas, each with its own role in speech motor control (Figure 1.1). The primary motor cortex can perhaps be thought of as a neuroplastic map whose internal organisation converts central signals about motor intentions into motor output commands, mediated by auditory and somatosensory feedback. The upper motor neurons of the primary motor cortex are modified by the premotor and somatosensory areas as new skills are practised (Dayan & Cohen, 2011). The pre-supplementary motor area (pre-SMA) is thought to be involved in the learning and adaption of motor sequences. The neighbouring supplementary motor area (SMA) takes input from the basal ganglia and the cerebellum to adjust the timing and rate of articulation. Although areas shown in Figure 1.1 are bilaterally active during simple speech tasks, the two hemispheres may play different roles during higher-level language tasks. Active language-related regions (not shown) of the cerebral cortex are generally left lateralised (Guenther, 2016).

1.3.2 Central Nervous System: Brainstem

The brainstem contains lower motor neurons and interneurons which are organised in clusters (nuclei), linked to muscles via the cranial nerves, numbered I to XII (Figure 1.2). These motor nuclei form a system of low-level muscle control stimulated by electrical synaptic discharges from the primary motor cortex which can be enhanced or suppressed by neuromodulation of levels of neurotransmitting chemicals. Motor nuclei share the brainstem with sensory nuclei and can utilise the inflow of afferent (auditory, somatosensory,

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