INTERFACE BETWEEN PHONOLOGY AND PHONETICS

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Introduction

The notion of an interface presupposes the existence of two discrete entities. The study of sound structure is commonly divided into phonology and phonetics. An understanding of the interface between them is thus dependent on how we delineate the two areas. Most theorizing about the relationship between phonology and phonetics acknowledges that there are both conceptual and physical aspects of sounds of human language. Phonology is often defined as the cognitive aspects of sound structures and sound patterns, while phonetics is understood to be the physical implementation of these structures and patterns. Under this view, phonology is what the speaker/hearer knows about the sound patterns of his/her language, and thus is uncontroversially part of the linguistic grammar. Phonetics, on the other hand, is what actually happens during the production and perception of these cognitive patterns. There are multiple ways phonology and phonetics interact. Phonological structure is realized through phonetic mechanisms, generally referred to as phonetic implementation, though researchers disagree about whether implementation should be viewed as a procedural, directional relationship. However, it is also clearly true that, phonetic considerations shape observed phonological patterns. There is much debate about whether this influence is direct and whether explanation of cross-linguistic phonological regularities resides within the phonetics. Three types of questions are often included in discussions of "the

phonology-phonetics interface". First, discussions about the interface are sometimes couched in terms of investigating the mechanisms that relate these two domains of knowledge of language. This is the most specific meaning of the relationship between phonology and phonetics. This, however, presupposes an answer to a second question: What is the *division of labor* between phonology and phonetics. This is a complex and controversial issue and both theoretical and empirical considerations come into play. Often implicitly included is a third question: What is the relationship between the academic *fields* of phonology and phonetics. In a strict sense only the first question is about the interface between aspects of knowledge of sounds, but because of the necessary precedence of the second question and common inclusion of the third in discussions about the interface, we discuss all three in this bibliography, We emphasize work that directly attends to the interface (in any of these senses). There is a large body of empirical and specifically phonetic work which informs these issues which could not be covered here, but many of these are in fact referenced by works discussed here.

Introductions to the Interface

In recent years there have been a number of excellent introductory articles on many aspects of the relationship between phonology and phonetics. To gain an overview of this relationship and to understand the range of views attributed to the interface, these articles are an excellent point of departure. These papers have appeared primarily in handbooks, and edited volumes. Earlier papers presuppose a clear division of labor between phonology and phonetics (influenced at least in part by generative phonology and a strictly modular view of the grammar), striving to understand the mechanisms relating the two and encouraging researchers to use more synthesizing approaches. Keating 1988 aims to educate the reader on how integration of phonetic and phonological methodologies offers better insights into each field. More recent papers grapple with growing evidence supporting the generally accepted conclusion that phonology and phonetics are not as distinct as previously assumed. This brings to the fore the question of the division of labor as well as the mechanisms involved in that division. Scobbie 2007 and Reiss 2007 offer two quite different views of the division and mechanisms. In line with the traditional generative phonology view, Reiss 2007 argues for a sharp contrast, while Scobbie 2007 emphasizes the lack of a sharp boundary, providing a particularly nuanced discussion, highlighting both empirical and theory-internal dimensions of the debate. Cohn 2007 attempts to clarify some of the different ways phonology and phonetics interact. Kingston 2007 revisits some of the core issues of the relationship, as does Hamann 2011 discussed in *Phonological and Phonetic Representations*. Ohala 2010 and Ladd 2011 provide historical framing

Cohn, Abigail C. 2007. Phonetics in phonology and phonology in phonetics. *Cornell Working Papers in Phonetics* 16: 1-31.
> Discusses two distinct ways phonology and phonetics interact. Discusses examples of assimilation and coarticulation at the core of debates over the "boundary" between phonology and phonetics , arguing that similar effects need not be attributed to identical grammatical machinery. Argues that the distinction between categorical phonology and gradient phonetics is empirically motivated.

Keating, Patricia A. 1988. "The phonology-phonetics interface." In *The Cambridge linguistic survey, vol. I: Linguistic theory: Foundations*. Edited by Frederick J. Newmeyer, 281-302. Cambridge: Cambridge University Press.
> A clear introduction oriented more toward the phonologist, focusing on features, phonetic implementation, and the phonetic basis of phonological units and processes. Some specific phonological theories referenced here have changed since this article was written but the issues raised about features and the relationship between grammatical modules are still key research

questions.

Kingston, John. 2007. "The phonetics-phonology interface." In *The handbook of phonology*. Edited by Paul de Lacy, 401-434. Cambridge: Cambridge University Press.

> Discusses three core ways phonetics relates to phonology: defining distinctive features (given the most attention), explaining phonological patterns and implementing phonological representations. Argues that the complexity of phonetics motivates phonological abstractions, and that the way phonetic substance affects phonological representations precludes a strict boundary between them.

Ladd, D. Robert. 2011. "Phonetics in phonology." In *Handbook of phonological theory (second edition)*. Edited by John. Goldsmith, Jason Riggle, and Alan Yu, 348-373. Oxford: Blackwell.

> Explores the dual role of speech sounds as physical events and elements in a symbolic system. Taking in part a historical perspective on the relationship between phonetics and phonology, critiques the widely held assumptions in phonology of a systematic phonetics involving a "segmental ideal" and a "universal categorization assumption" (p. 349).

Ohala, John J. 2010. "The relation between phonetics and phonology." In *The handbook of phonetic sciences, second edition*. Edited by William J. Hardcastle and John Laver, 653-677. Oxford: Blackwell.

> Provides an historical perspective and then identifies key questions that must be considered about the relationship between phonology and phonetics. It addresses not only phonetics and phonology, but also brings language change into the discussion. Excellent historical review and clear framing of the questions critical to the field.

Reiss, Charles. 2007. "Modularity in the 'sound' domain: Implications for the purview of universal grammar." In *Oxford handbook of linguistic interfaces*. Edited by Gillian Ramchand and Charles Reiss, 53-78. Oxford: Oxford University Press.

> In line with earlier generative views, presents a strictly modular view of the interface where only phonology is part of "universal grammar," defining the abstract sound properties of the set of logically computable languages. The "substance" of sound structure falls to the phonetics, historical change, and other "extragrammatical" factors.

Scobbie, James M. 2007. "Interface and overlap in phonetics and phonology." In: *Oxford handbook of linguistic interfaces*. Edited by Gillian Ramchand and Charles Reiss, 17-52. Oxford: Oxford University Press.

> Employing an analogy with tidal zones, argues forcefully that phonetics and phonology are clearly distinct, yet there are true intermediate cases that do not belong to either domain. Arguing for an empirical approach that assumes little a priori, the author favors detailed representations like those proposed within exemplar theory.

Resources

There are a number of easily accessible resources that can aid in the quantitiative investigation of sound structure and the interface between phonology and phonetics. While an exhaustive list is well beyond the scope of this article, included here are a few key widely-used resources. **Praat**, developed by Boersma and Weenink, is free acoustic analysis software widely used throughout the field. **The International Phonetic Association** provides information about the International Phonetic Alphabet and other resources useful for the transcription and documentation of the sound inventories of language. The updated **UCLA Phonological Segment Inventory Database** database (see Maddieson 1984 cited

under *Phonetic Explanations of Sound inventories*) is available for download and in a searchable online version. **PBase version 3**, developed by Mielke, also provides a searchable segment inventory based on phonological processes in several hundred languages. **The World Atlas of Language Structure** includes a number of phonological topics, with maps of the distribution of various phonological phenomena. The **UCLA Phonetics Lab Language Archives** makes available audio recording of sounds in over 200 languages. Beckman et al. 2005 describes the basic properties of ToBI, a system for annotating prosodic properties of language, including the relationship between word boundaries, tones, and prosodic breaks due to different levels of phonological phrasing.

Beckman, Mary E., Hirschberg, Julia, and Stephanie Shattuck-Hufnagel. 2005. The original ToBI system and the evolution of the ToBI framework. *Prosodic typology: The phonology of intonation and phrasing.*. Edited by Sun-Ah Jun, 9-54. Oxford: Oxford University Press.
>   Describes the founding principles of ToBI as well as theoretical considerations which drove the design of the system. The framework has facilitated an increase in the number of languages whose prosodic characteristics are being studied, as versions are developed for an increasing number of languages.

Pbase version 3[http://137.122.133.199/cgi-bin/pbase3/search.cgi] By Jeff Mielke.
>   The most recent version of Jeff Mielke's searchable segment inventory allows the user to search for the occurrence of particular sounds as part of phonologically active classes. This can be used to test various predictions about cross-linguistic patterns within phonological inventories.

Praat: Doing Phonetics by Computer[http://www.fon.hum.uva.nl/praat/] By Paul Boersma and David Weenink.
>   Free format neutral software for doing acoustic phonetic analysis. Widely used by linguists throughout the world; analysis of audio files in .wav format. The associated website provides access to several very helpful manuals as well as an online forum of users who can assist with questions about the program.

The International Phonetic Association[http://www.langsci.ucl.ac.uk/ipa/].
>   Provides information about the International Phonetic Alphabet, sound recordings accompanying illustrations of the alphabet and other resources helpful for phonetic transcription, phonetic description and analysis.

The World Atlas of Language Structures Online database (WALS)[http://wals.info/] Edited by Matthew Dryer and Martin Haspelmath. Munich: Max Planck Digital Library.
>   Provides an extensive database of structural properties of language plotted geographically, contributed by 55 specialists. Phonological structures of interest here include segment type, alternations, and syllable structure.

UCLA Phonetics Lab Language Archive[http://archive.phonetics.ucla.edu/].
>   Makes available in searchable form, audio recordings made over a 50 year period at the UCLA phonetics lab, illustrating phonetic structures for over 200 languages.

UCLA Phonological Segment Inventory Database[http://www.linguistics.ucla.edu/faciliti/sales/software.htm].By Ian Maddieson and Kristin Precoda
>   A downloadable database, with accompanying software, containing data on phonemic systems in

451 languages. Both the software and online interface allow the user to investigate the distribution of sounds and sound inventories across the representatively chosen inventories. Online searchable interface is available*online[http://web.phonetik.uni-frankfurt.de/upsid.html]*, developed by Henning Reetz.

Phonetics within a Broader Phonology

The relationship between phonology and phonetics is sometimes taken as a subtopic within the field of phonology. de Lacy's 2011 bibliography in this series defines phonology broadly, including introductions to the various interfaces, while providing a good introduction to the phonological literature more generally. Several recent handbooks and companions to phonology treat the interface as a phonological topic. The journal **Phonology** also takes this broad view. The newly released 2nd edition of *The Handbook of Phonological Theory*, (Goldsmith et al. 2011) includes chapters on many of the interfaces between phonology and other domains, including the phonology-phonetics interface. Van Oostendorp et al. 2011 takes a broad definition of phonology, including a number of chapters about the interfaces and relationships of phonology to other domains. De Lacy 2007 provides an introduction to core topics in phonology as well as its interfaces, largely from the theoretical perspective of Optimality Theory. Kula et al. 2011 offers a particularly broad definition of phonology, addressing both methodological approaches and research topics. All of these reference works include accessible topic-specific discussion of these and related questions, and extensive bibliographies. Many chapters from these works appear as individual entries in this bibliography, as they provide informative introductions to the topics included here.

de Lacy, Paul, ed. 2007. *The Cambridge handbook of phonology*. Cambridge, UK, and New York: Cambridge University Press.
> Offers clear introductions to the core areas of phonology, including phenomena to be accounted for, largely from the theoretical perspective of Optimality Theory. Theoretically oriented chapters are accessible and well-framed. Also includes interfaces and closely related areas. See entries in *Introductions to the Interface* and *Phonetic Implementation of Prosody*.

de Lacy, Paul. 2011. *Phonology*. *Oxford Bibliographies[http://www.oxfordbibliographies.com/]*.
> An expansive introduction to the field of phonology, including the phonology-phonetics interface and other interfaces. Excellent starting point for more basic references in phonology, including textbooks, standard references, history of phonology, and background on many of the phenomena that are at the core of debates over the phonology-phonetics interface.

Goldsmith, John, Jason Riggle, and Alan Yu, eds. 2011. *Handbook of phonological theory*, 2nd edition. Oxford: Wiley-Blackwell.
> The 2nd edition is completely revised and offers accessible up-to-date chapters on both major topics internal to phonology and the relationship between phonology and several closely allied fields, including the relationship between phonology and phonetics. See entries in *Introductions to the interface*, *Psycholinguistics and processing* and *First Language Acquisition*.

Kula, Nancy C., Bert Botma, and Kuniya Nasukawa, eds. 2011. *The continuum companion to phonology*. London and New York: Continuum [renamed *The Bloomsbury Companion to Phonology*].
> This volume complements the others in this section. It is organized around methodological issues in phonology, research topics, new directions, and a historical overview. See entries in *Phonological and Phonetic Representations*, *Phonetic Implementation of Prosody*, *Second Language Learning* and *Integrated Views*.

Van Oostendorp, Marc, Colin J. Ewen, Elizabeth V. Hume and Keren Rice, eds. 2011. *The Blackwell companion to phonology,* 5 Vols. Oxford: Wiley-Blackwell.

> This five volume set with 124 chapters covers a wide range of topics in phonology. Volume 4 specifically addresses interfaces with phonology. Several chapters touch on the relationship between phonology and phonetics. See entries in * Distinctive Feature Theory and Primitives of phonological Sound Structure*, *Laboratory Phonology*, *The Boundary between Phonology and Phonetics*, *Phonologial and Phonetic Representations*, and *Insights from Perception*.

Phonology (formerly *Phonology Yearbook*), Cambridge: Cambridge University Press.

> The only journal devoted solely to phonology (volumes I-IV published as *Phonology Yearbook*). While theoretically oriented, also includes rich empirical findings and embraces experimental approaches to phonology as an important method in phonology. See thematic issues, including vol. 3, 1986, vol. 18.1 2001, vol. 26.1 2009.

Collections Addressing the Interface

There are a number of collections that address diverse aspects of the relation between phonology and phonetics. Many of these grew out of workshops or conferences addressing the relationship in general, or addressing more specific topics from multiple approaches. The introductions to these volumes usually give a helpful overview and guide the prospective reader to see which specific articles might be of interest. Some of the best work on the interface appears in these volumes, as the papers respond to a shared discussion and often provide detailed analysis of one or more specific empirical domains or problems. Some have appeared as stand-alone edited works, while others have appeared as special thematic issues of journals. A number of these are included throughout the bibliography. Those works specifically focused on Laboratory Phonology are addressed in a separate section *Laboratory Phonology*. This section contains several influential volumes whose topics cut across the themes discussed in this article. The *Phonology and Phonetics Series*, Lahiri, ed. 2001-, includes a number of volumes directly relevant to the interface. The **Journal of Phonetics** also offers extensive contributions of experimental work that informs phonological structure, including a number of recent special thematic volumes. Burton-Roberts et al. 2000 and Durand and Laks 2002 both provide empirically rich discussions of the relationship between the cognitive and physical as they are mediated by phonology. Ohala and Jaeger 1986 is an early and influential work which demonstrates a variety of ways that phonetic methods of analysis can be applied to enrich our understanding of ideas taken to be fundamental assumptions in phonology. This perspective is one of the fundamental premises of the later laboratory phonology community (see *Laboratory Phonology*). Solé et al. 2007 provides an even broader presentation of the vast variety of experimental approaches to understanding speech. Hardcastle and Hewlett 1999 brings a set of diverse perspectives to a more focused topic, that of coarticulation—the effect of one sound on a neighboring sound—a problem that has been at the core of many discussions of the relationship between phonetic and phonology.   Another particularly influential collection is Hume and Johnson 2001 (cited under *Insights from Perception*). A number of individual papers from these volumes appear throughout the bibliography.

Burton-Roberts, Noel, Carr, Philip and Gerard J. Docherty, eds. 2000. *Phonological knowledge: conceptual and empirical Issues,* Oxford: Oxford University Press.

> Ensemble of papers exploring the conceptual and empirical foundations of phonological knowledge in its relationship to linguistic theory, phonetics, cognition and acquisition. Excellent collection of papers from experts in these related fields, all of whom take an integrated approach to the cognitive and physical aspects of speech.

Durand, Jacques and Bernard Laks, eds. 2002. *Phonetics, phonology, and cognition*, Oxford: Oxford University Press.

> Provides several views of the "cognitive status of phonological representations and their relationship with phonetic implementation" (p. 1) through a number of experimentally rich chapters. Brings together phonetic work (both production and perception) and psycholinguistic and neurolinguistic work as they inform phonological representation (including the segment and the syllable).

Hardcastle, William J. and Nigel Hewlett, eds. 1999. *Coarticulation: Theory, data and techniques.* Cambridge: Cambridge University Press.

> An articulatorily focused treatment of coarticulation, a topic which invokes many of the longstanding issues in relating discrete symbolic representations to more or less continuous physical change. Chapter 2 (pp.31-68) reviews models of coarticulation. Chapter 9 (pp. 199-227) discusses implications of data on coarticulation for phonology and theories of the phonetics:phonology relation.

Journal of Phonetics, Elsevier, http://www.journals.elsevier.com/journal-of-phonetics/.

> A key journal in linguistic phonetics. Includes experimental phonetics work that informs questions of phonological representation, structure, and processing. Articles in general issues, as well as recent thematic issues, often address topics of the relationship and interface between phonology and phonetics.

Lahiri, Aditi, ed. *Phonology and Phonetics Series [http://www.degruyter.com/view/serial/16239]*. 2001-, Berlin: de Gruyter Mouton.

> First published in 2001, eighteen volumes have appeared to date (including LabPhon vols. 7-10). "Intended as a forum for the interaction of phonology and phonetics within linguistics," http://www.degruyter.com/view/serial/16239 accessed 7/11/13.

Ohala John, J. and Jeri J. Jaeger, eds. 1986. *Experimental phonology*. Orlando, FL: Academic Press.

> Introduces a rich set of experimental approaches to questions about phonological knowledge, including phonetic explanations for phonological universals and laboratory tests for assessing the psychological reality of phonemes. Demonstrates a variety of ways that phonetic methods of analysis can test fundamental assumptions in phonology.

Solé, Maria-Josep, Patrice Beddor and Manjari Ohala. eds. 2007. *Experimental approaches to phonology*. Oxford: Oxford University Press.

> A diverse volume with many papers on phonetic explanations of phonological universals and sound change. Papers also highlight the complexity of the relation between physical properties and linguistic structures of phonological and lexical contrast. Several papers make innovative proposals for future investigation of the phonetics: phonology relation.

Laboratory Phonology
One particularly fruitful approach to investigating the interface between phonology and phonetics has been the application of varied experimental approaches to phonology, termed *laboratory phonology*. Growing out of the first Laboratory Phonology (LabPhon) conference in 1987, this has now become an established approach to understanding the cognitive and physical dimensions of human speech. The volumes *Papers in Laboratory Phonology I-10* and the newly founded journal *Laboratory Phonology* provide a wealth of reading within this perspective. . Ohala and Jaeger 1986, (cited under *Collections

Addressing the Interface*) predating the first laboratory phonology conference, was at the vanguard of this approach. Cohn et al. 2012 offers a comprehensive introduction including multiple contributions about the nature of representation, variation, and lexical knowledge, as well as methods for studying these issues   Pierrehumbert et al. 2000 argues for the laboratory phonology approach, outlining critical shared scientific goals of the community that benefit scientific progress. Kawahara 2011 provides a rich summary of work done within the laboratory phonology perspective, on several key topics from an experimental perspective.

Cohn, Abigail C., Cecile Fougeron and Marie K. Huffman, eds. 2012. *The Oxford handbook of laboratory phonology*. Oxford: Oxford University Press.
>   Surveys current research in laboratory phonology, an empirical, interdisciplinary approach to relating phonetic and phonological phenomena. Many of the chapters deal directly with questions of linguistic representation and the relation between phonology and phonetics. Other themes include the nature of phonetic variation and promising research methods for the field.

Kawahara, Shigeto. 2011. "Experimental approaches in theoretical phonology." In *The Blackwell companion to phonology*. Edited by Marc van Oostendorp, Colin J. Ewen, Elizabeth V. Hume, and Keren Rice. 2283-2303. Oxford: Wiley-Blackwell.
>   Clear introduction to several domains of experimental work in phonology. After reviewing history of the relationship, discusses the ways that "experimental work has informed phonology, and vice versa" p. 1 online version. Excellent review of core topics of debate with extensive references. Highlights methodologies that have advanced our understanding of these topics.

Laboratory Phonology. The journal of the Association for Laboratory Phonology, DeGruyter Mouton http://www.labphon.org/home/journal.
>   Founded in 2010, this journal supersedes *Papers in Laboratory Phonol*ogy as the venue for publication of papers presented at LabPhon. Addresses experimental approaches to the investigation of sound structure, drawing together work in phonology, phonetics, computational linguistics, psycholinguistics, etc.

Papers in Laboratory Phonology I-10. Volumes I-VI, Cambridge: Cambridge University Press. Volumes 7-10, Berlin: de Gruyter Mouton.
>   The proceedings volumes from the first 10 LabPhon conferences. First four volumes focus primarily on issues about the relationship between phonology and phonetics, including use of experimental data to elucidate the nature of phonology and its mapping to phonetics. Since LabPhonV, issues covered broadened considerably to include topics such as psycholinguistics, computational modeling and sociophonetic variation.

Pierrehumbert, Janet B., Beckman, Mary E. and D. Robert Ladd. 2000. "Conceptual foundations of phonology as a laboratory Science." In *Phonological knowledge: Conceptual and empirical Issues*. Edited by Noel Burton-Roberts, Philip Carr, and Gerard Docherty, 273-303. Oxford: Oxford University Press (reprinted in Cohn, Fougeron, and Huffman 2012).
>   Provides a conceptual framing of laboratory phonology, discussing the philosophical underpinnings of approaches to studying phonology. Discussion put in the broader context of the natural sciences, highlighting the need for experimental quantitative methods to study sound structure scientifically.

Approaches to the Interface

Here the nature of the interface itself and the kinds of models that have been developed to characterize the "mapping" are addressed more specifically. First in *Phonetic Implementation of Prosody* and *Phonetic Implementation of Segmental Structure* we address the empirical issues of implementation of these aspects of phonological structure, while also providing some historical perspective. In this part of the bibliography, unlike other sections, we devote separate sections to prosody and segmental structure. In *Articulatorily Based Approaches* work on implementation taking a gestural or articulatory approach, including Articulatory Phonology, is reviewed.   In *Integrated Views*, approaches that do not draw a distinction between the mechanisms of phonology and phonetics are reviewed, and in *Insights from Perception* perceptually based models, and work emphasizing the role of perception in influencing phonological structure, are discussed.

Phonetic Implementation of Prosody

Phonetic implementation, that is, how phonological patterns are implemented in physical time and space, is one of the core topics of the phonology-phonetics interface. One way it has been modeled is through the connection of sparse static phonological representations in physical time and space. As a class, these models – target- interpolation and other forward-feed models – aim to connect presumably discrete linguistic modules. The modeling of prosody more generally played a central role in the development of an understanding of the relationship between phonology and phonetics.. The empirical problems posed by the phonetic realization of pitch, drove much of the rethinking of aspects of the mapping as evidenced notably by Pierrehumbert's 1980 MIT dissertation. **below as entry** on the implementation of intonation in English. Pierrehumbert's general approach was extended to other languages and to other phonological dimensions. Pierrehumbert and Beckman 1988 further develops this approach with an in-depth integrated account of Japanese pitch accent,. Jun 2005 and Ladd 2008 are both empirically rich books on the phonology and phonetics of intonation and prosody more generally In both cases, these works are broader than suggested by the respective titles, addressing not only the phonology of intonation, but also its implementation.   These works provide a framework to understand prosody typologically. Frota et al. 2011 addresses the implementation and processing of prosody. Arvaniti 2011 (see *Phonological and Phonetic Representations*) also reviews our understanding of implementation of prosody while focusing on representations of prosody. While the ToBI framework (see *Resources*) has been very helpful in offering an account of intonational phonology and a framework for implementation, Arvaniti, Ladd, and colleagues (e.g. Arvaniti et al. 2006) highlight some of the finer details needed in an adequate model of tonal alignment. One ongoing debate in the literature has been whether a unified account of implementation of pitch as realized in both intonation and tone is possible and desirable. Gussenhoven 2007 provides a model for implementation of prosodic structure that offers a unified approach. Xu 2005 addresses the further issue of the linguistic functions of pitch as they relate to broader communicative functions and how these are best integrated into an adequate account. Cho 2011 discusses a range of issues at the prosody-phonetics interface, providing a rich review of empirical studies as well as a concise summary of various approaches to the implementation of prosody.

Arvaniti, A., D. R. Ladd and I. Mennen. 2006. Tonal association and tonal alignment: Evidence from Greek polar questions and contrastive statements. *Language and Speech* 49: 421-450.

> Investigates the production and perception of superficially similar pitch contours in Greek, and argues that the differences can be accounted for in terms of tonal composition (that is, phonological representation) and phonetic alignment of these tunes.   Highlights the linguistic significance of such subtle differences.

Cho, Taehong. 2011. "Laboratory phonology." In *The continuum companion to phonology*. Edited by Nancy Kula, Bert Botma, and Kuniya Nasukawa, 343-368. London/New York: Continuum.
> Despite the more general title, this work focusses on the phonetics-prosody interface. After a brief review of the historical relationship between phonology and phonetics, it provides a detailed summary of empirical findings in prosodic realization of phonological patterns, particularly prosodic strengthening effects, and reviews models of implementation of prosody.

Frota, S.; Elordieta, G.; Prieto, P. eds. 2011. *Prosodic categories: production, perception and comprehension* (SNLT Collection). Springer Verlag: The Netherlands.
> Edited volume addressing the implementation and processing of prosodic categories, advancing our understanding of the role of prosody in production, perception, and comprehension. Offers introduction to extensive recent experimental work on a range of experimental paradigms investigating prosody in a wide range of languages.

Gussenhoven, Carlos. 2007. "The Phonology of Intonation." In *The Cambridge handbook of phonology*. Edited by Paul de Lacy, 253-280 . Cambridge*:* Cambridge University Press.
> A clear overview of basic issues in intonational representation, including the basic elements of tonal implementation models, the evidence for phonetic underspecification of tones and many examples of language specific aspects of tonal implementation in intonation.

Jun, Sun-Ah. ed. 2005. *Prosodic Typology: The phonology of intonation and phrasing*. Oxford: Oxford University Press.
> Edited volume with CD-ROM with sketches of the intonational systems of 11 languages, within the ToBI framework; includes introduction to ToBI and a chapter on typology of prosody. Paperback edition also includes updated references to work on intonation and ToBI.

Ladd, D. Robert. 2008. *Intonational phonology, 2nd Edition*. Cambridge: Cambridge University Press.
> Accessible introduction to both the empirical problems and theoretical approaches used to understand the phonology of intonation and its phonetic implementation. Includes review of issues posed by intonation of English while also offering a cross-linguistic perspective. Excellent starting point for the study of intonation and prosody more generally.

Pierrehumbert, Janet B. 1980. *Phonology and phonetics of English intonation tone structure*, Linguistic PhD thesis, MIT, distributed 1988, Indiana University Linguistics Club.
> Presents an explicit model of English intonational contours, from phonological representations to F0 values. This work launched a whole new approach to modeling of the relation between phonology and phonetics, both for tone and segmental features.

Pierrehumbert, Janet B. and Mary E. Beckman. 1988. *Japanese tone structure*, Linguistic Inquiry Monograph 15, MIT Press, Cambridge.
> Presents a detailed model of tonal implementation for Tokyo Japanese, based on extensive phonetic analysis, offering a unified account of phonological and phonetic prosody. Employs reference to multiple levels of prosodic structure and tonal underspecification, contrasting with earlier feature spreading accounts Introductory chapter provides a concise introduction to the approach.

Xu, Yi. 2005. Speech melody as articulatorily implemented communicative functions. *Speech Communication* 46: 220-251.

Addresses multiple dimensions of pitch in language. Proposes a model of melodical primitives to account for linguistic patterns of tone and intonation, implemented within an articulatory model. Emphasizes the need to understand linguistic uses of pitch within its broader communicative functions.

Phonetic Implementation of Segmental Structure

Research modeling the phonetic realization of pitch inspired analogous research on phonetic implementation of segmental properties which addresses both similar and complementary issues. This work on the nature of the mapping inspired a number of specific models of implementation. Keating 1996 provides a concise introduction to target-interpolation views of phonetic implementation. Keating 1990 proposes a specific model of segmental implementation which includes a range of abstract articulatory or acoustic targets (windows) that inherently allow for variation. Cohn 1990 provides a feature-driven target-interpolation account for phonetic and phonological modeling of nasal airflow patterns in three languages. Boyce et al. 1991 presents articulatory data in support of gestural rather than featural representations, attributing much of coarticulatory variability to temporal effects on gestural dynamics. Lindblom 1989 argues for representations that involve somewhat abstracted goals without committing to a choice between their articulatory versus acoustic/perceptual nature. Its discussion of economy, especially conceived as articulatory economy, has been much cited. Some earlier literature within speech technology, especially synthesis, also offers formal implementations of the relationship between phonological goals and physical dimensions. An example of a paper that integrates phonology and phonetics from a speech technology perspective is Hertz and Clements 1996. (More recent approaches to synthesis, which depend largely on concatenation or stored acoustic recordings, do not connect so directly with linguistic modeling of the mapping). Fujimura 2000 proposes an abstract form of phonetic representation in which segmental and prosodic factors are integrated equally into a model of articulatory planning. Clearly one's view of implementation depends crucially on one's view of phonology; see also *Division of Labor*.

Boyce, Suzanne, E., Rena A. Krakow and Fredericka Bell-Berti.1991. Phonological underspecification and speech motor organization. *Phonology* 8: 219-236.

Using articulatory data on velum and lip position, argues against underspecification in phonetics. Highlighting task factors (e.g., rate) and linguistic context as effects on articulatory targets, shows the importance of careful methodology and nuanced interpretation in investigating the relation between phonological entities and output of the speech production process.

Clements, G. Nick and Susan R. Hertz. 1996. "An Integrated Approach to Phonology and Phonetics." In *Current trends in phonology*. Edited by Jacques Durand and Bernard Laks, 143-74. University of Salford: University of Salford Publications.

Uses regularities and variability in acoustic data to argue for representations that coordinate abstract phonological information with temporal information about acoustic targets. Proposes an integrated feed-forward system in which surface phonological representations map onto separate articulatory and acoustic phonetic representations.

Cohn, Abigail C.1990. *Phonetic and Phonological Rules of Nasalization*. UCLA Working Papers in Phonetics 76. Los Angeles: Department of Linguistics, UCLA.

Presents detailed proposals for target-interpolation models of feature-based phonetic implementation to account for phonetic and phonological patterns of nasalization in French, English and Sundanese. Highlights role of phonological specification and underspecification in shaping language specific patterns of phonetic realization.

Fujimura, Osamu. 2000. The C/D Model and Prosodic Control of Articulatory Behavior. *Phonetica* 57:128–138.

> A proposal for phonetic representation and implementation that takes the syllable as a foundational unit and treats prosodic and segmental influences on equal footing in planning articulation. Argues for a separate but more abstract phonetics that can generate coarticulatory as well as language specific and prosodic contextual effects.

Keating, Patricia A. 1990. "The window model of coarticulation: articulatory evidence." In *Papers in Laboratory Phonology I* . Edited by John Kingston and Mary Beckman. Cambridge: Cambridge University Press, 451-470.

> Outlines a proposal for segmental implementation employing ranges of target values (windows) defined by feature specification and possibly language specific phonetics. Interpolation functions select a path through successive windows. Both windows and interpolation explicitly allow for variability, helping account for the wide range of variation observed in coarticulatory effects.

Keating, Patricia A. 1996. "The phonology-phonetics interface." In *Interfaces in phonology*. Edited by Ursula Kleinhenz, 262–278. Studia Grammatica. Berlin: Akademie Verlag.

> Introduces target interpolation models and Articulatory phonology as approaches to relating phonology and phonetics, highlighting the role of underspecification in phonetics. Introduces the Window model in which value ranges are targets and featural specification influences window width. Interpolation is accomplished by a family of functions that meet the window requirements.

Lindblom, Bjorn. 1989. "Explaining phonetic variation: a sketch of the H&H theory" in *Speech production and speech modeling*. Edited by William Hardcastle and Alain Marchal, 403-439. Dordrecht, The Netherlands: Kluwer Academic Publishers.

> Proposes a view in which system oriented considerations of economy interact with output-oriented behavior. This view sidesteps the invariant representation: variable realization dilemma, arguing for a continuum of possible realizations from hypo- to hyperspeech where the latter satisfies economy and the former demonstrates plasticity in service of communicative clarity.

Articulatorily based approaches

One's view of phonetic implementation, or more generally the relationship between phonology and phonetics, is profoundly affected by one's assumptions about the form of core phonological representations. A number of researchers have argued for articulatorily defined linguistic representations. Articulatory Phonology is the most widely studied and influential of these alternatives to a modular, derivational view of the relation between phonology and phonetics. By arguing that lexical representations include gestures with explicit timing relations, the theory bypasses some of the problems in defining where a discrete symbolic (phonological) representation ends and a temporally embellished (phonetic) one begins. Work in Articulatory Phonology has offered alternative accounts to a wide range of phenomena which were handled previously with phonological categorical feature changing or segment deletion rules. Browman and Goldstein 1992 is one of the most detailed early papers outlining the basic principles of Articulatory Phonology.   See also Browman and Goldstein 1990 in *Phonetic explanations for phonological patterns* and contributions in *Phonological and phonetic representations* and *Second language learning*. Beňuš, and Gafos 2007 argues that a dynamical account could provide a superior explanation of "phonological" data on vowel harmony and its exceptions. Gafos 2006 is a detailed example of work applying a dynamical systems approach to the elaboration of how gestural targets may vary, thus providing an account of many of the sources of surface phonetic variation that have been a

challenge to accounts of the phonology:phonetics relation. Goldstein et al. 2007 provides important new kinematic evidence in favor of gestures as fundamentals of speech planning, showing that speech errors (commonly taken as important evidence that segments are a primary unit of speech planning) conform to general principles of gesture timing and phasing. Tilsen and Goldstein 2012 provides complementary data on speech gestures as possible control units as evidenced in artificially halted speech. Byrd and Saltzman 2003 strengthens the empirical coverage of articulatory approaches, arguing that prosodic effects on gestures observed at domain edges can be modeled by including a prosodic gesture in representations. Kingston 2007 (cited under *Introductions to the Interface*), in contrast, argues that linguistically relevant targets are auditory/acoustic, which implies that the insights and mechanisms of Articulatory Phonology need to be incorporated into a broader view of linguistic representation.

Beňuš, Stefan and Adamantios Gafos. 2007. Articulatory characteristics of Hungarian 'transparent' vowels. *Journal of Phonetics* 35: 271-300.
> Argues that phonological behavior of transparent vowels is better understood when phonological patterning is studied together with articulatory and acoustic characteristics. Magnetometry and ultrasound data show backness harmony effects, even without a triggering suffix present, suggesting a phonetic quantal basis for harmony patterns and evidence for exemplar representations.

Browman, Cathe and Louis Goldstein. 1992. Articulatory Phonology: An Overview, *Phonetica* 49: 155-80.
> Presents core assumptions of Articulatory Phonology, arguing that representations in terms of coordinated gestures provide more insightful accounts of a variety of phenomena (e.g., segment reduction and deletion in connected speech, stop voicing allophones) which traditional phonological descriptions have described as categorical feature changing or segment deletion rules.

Byrd, Dani and Elliot Saltzman. 2003. The elastic phrase: Modeling the dynamics of boundary-adjacent lengthening. *Journal of Phonetics* 31,2: 149-180.
> Proposes that phonological representations include a pi gesture, which produces slowing of nearby articulatory gestures. This innovation allows for an account of phrase boundary related lengthening in terms of Articulatory Phonology, obviating the need for an interpretive mechanism to transduce phrase edges into changes in gestural parameters.

Gafos, Adamantios. 2006. "Dynamics in Grammar: Comment on Ladd and Ernestus & Baayen." In *Laboratory phonology 8: Varieties of phonological competence*. Edited by Louis Goldstein, Doug Whalen and Catherine Best, 51-79. Berlin/New York: Mouton de Gruyter.
> Taking incomplete neutralization of consonant voicing as a test case, illustrates how dynamical systems can model both phonological and non-linguistic contextual influences on articulation. The dynamical approach is offered as an alternative view of the phonetics-phonology interface, and the need to relate qualitative and quantitative aspects of speech.

Goldstein, Louis, Marianne Pouplier, Larissa Chen, Elliot Saltzman, and Dani Byrd. 2007. Dynamic action units slip in speech production errors. *Cognition* 103, 386-412.
> Uses kinematic data to argue against the common view that whole segments are interchanged in speech errors. Instead, individual component gestures of a sound can participate in an error, with intrusions dominating reductions. Intrusions are attributed to the shift of gesture phasing to a more stable mode of frequency locking.

Tilsen, Samuel and Louis Goldstein. 2012. Articulatory gestures are individually selected in production. *Journal of Phonetics,* 40: 764-779
> Uses articulatory tracking data in a forced speech-halting paradigm, arguing that speakers individually control the component gestures of a speech sound when planning speech. The results challenge theories which assume that segment sized units are the minimal units referenced in speech planning.

Integrated Views

In recent years there has been extensive critique of strictly modular views of the interface between phonology and phonetics. This criticism has taken a number of forms and results in different alternative approaches. These alternatives are often functional in nature, arguing that physical and cognitive constraints on sound structure are the primary determinant of the shape/nature of the phonological system. They also tend to be usage-based approaches, holding that language structure and use are inextricably intertwined, even to the extent that there is not a sharp distinction between discrete and variable aspects of speech. Silverman 2011 provides an informative and accessible overview of functional and usage-based accounts as they relate to individuals and speech communities. Two general types of approaches have been taken to integrating mechanisms for the modeling of discrete and variable aspects of sound systems. Within Optimality Theory, there have been a number of specific proposals, including Grounded Optimality Theory, Stochastic Optimality Theory, and Harmonic Grammar, which have in common the ranking of violable constraints. Hayes et al. 2004 provides a rich introduction to Grounded OT. Flemming 2001 is an excellent example of such an integrated approach. For a review of a number of different accounts to variability and optionality in phonology, see Coetzee 2012. (Note only some of this body of literature is relevant to issues of the interface between phonology and phonetics.) A very different approach is exemplar theory, which holds that stored knowledge about speech includes traces of each utterances that the speaker/hearer is exposed to and that "categorization proceeds from *experience* with actually sensory objects: perceptual categories emerge from *repeated exposure* to similar sensory objects" (Silverman 2011 p. 381). The first serious linguistic discussion of exemplar theory as applied to sound structure is provided in a now classic paper, Johnson 1997. Pierrehumbert 2001 also provides an explicit discussion of the implementation of exemplar theory to sound structure. See Silverman 2011 for recent discussion and review of relevant literature.

Coetzee, Andries. 2012. "Variation: where laboratory and theoretical phonology meet." In *Oxford handbook of laboratory phonology*. Edited by Abigail C. Cohn, Cécile Fougeron, and Marie K. Huffman, 62-75. Oxford: Oxford University Press.
> After reviewing evidence for the importance of experimental data in describing variable and gradient patterns in phonology, discusses various integrated approaches for modeling gradient and categorical and grammatical and extra-grammatical factors together within formal phonological models. Helpful summary of the empirical issues and current approaches.

Flemming, Edward. 2001. Scalar and Categorical Phenomena in a Unified Model of Phonetics and Phonology. *Phonology* 18: 7-44.
> Argues for a strong *phonetics in phonology* approach in which language specific phonetic details of phonetic structure are controlled by weighted constraints, thus using the same basic mechanism to account for similar phonological and phonetic phenomena.

Hayes, Bruce, Robert Kirchner, and Donca Steriade, eds. 2004. *Phonetically based phonology*, Cambridge: Cambridge University Press.
> Discusses sources of markedness in phonology, largely from a phonetically grounded Optimality-

theoretic perspective. Presents different ways of modeling effects of phonetics on phonology, including ones that do not draw a formal distinction between phonology and phonetics. Introduction (see *Integration of Phonetic Influences in Phonology*) provides an excellent orientation to the issues.

Johnson, Keith. 1997. "Speech perception without speaker normalization: An exemplar model." In *Talker variability in speech processing*. Edited by Keith Johnson and John W. Mullennix, 145-165. San Diego: Academic Press.

> Advocates an exemplar approach to mental representation of sounds, focusing on the problem of normalization across speakers, a key challenge to theories of abstract lexical representations of speech. Key elements of an exemplar account are outlined and demonstrated with simulations based on data from behavioral speech perception experiments.

Pierrehumbert, Janet B. 2001. "Exemplar Dynamics: Word Frequency, Lenition and Contrast", in *Frequency and the emergence of LInguistic structure.* Edited by Joan Bybee and Paul Hopper, 247-57. Amsterdam: Johns Benjamins.

> Elaborates and demonstrates how an exemplar model could handle a variety of generalized effects on pronunciation including word frequency effects, lenition and the establishment and neutralization of contrasts, arguing that in many cases the exemplar approach provides a better account than that available in more traditional generative models.

Silverman, Daniel. 2011. "Usage-based Phonology." In *The continuum companion to phonology.* Edited by Nancy Kula, Bert Botma, and Kuniya Nasukawa, 369-394. London/New York: Continuum.

> Reviews usage-based approaches that investigate the discrete and variable nature of phonology without drawing a priori distinctions. Discusses work that models these patterns and tries to explain them with functional, self-organizing systems. Highlights critical importance of work by Labov and Ohala and other earlier literature as precursors to current approaches.

Insights from Perception

For a long time phonology has had a decidedly articulatory bias. This was seen both in assumptions about distinctive feature theory, largely defined articulatorily (see *Distinctive Feature Theory and Primitives of Phonological Sound Structure*, also Ladefoged 1988 in *The Boundary between Phonology and Phonetics*), as well as the modeling of phonological systems which privileged production (see *Phonetic Implementation of Prosody* and *Phonetic Implementation of Segmental Structure*). This issue was brought to the fore in Hume and Johnson 2001, an important volume based on a symposium on this topic, providing an introduction to various ways that perception can affect phonology, and vice versa. While consensus on the importance of perception as a factor in phonology has grown, the issue of how this influence should be integrated into formal models of phonology remains. A recent overview of the various relationships between perception and phonology is presented in Martin and Peperkamp 2011, while Boersma and Hamann 2009 presents different approaches to modeling the relationship. Flemming 2005 provides a review of the evidence and recent approaches to incorporation of perception within a constraint-based approach. Steriade 2001/2009 develops a model of direct effects of perception on phonology through the proposed P-Map. See also Flemming 2001 in *Integrated views* for a specific example of how perceptual constraints can be modeled in Optimality Theory. Further, Lahiri and Reetz 2010 in *Phonological and phonetic representations* argues that abstract lexical representations offer an account of how hearers successfully process the variability of language. Hawkins 2003 argues strongly against limiting mental representations for speech to sparse linguistically abstract representations processed via unidirectional parsing algorithms. Nguyen 2012 surveys recent results in perception and

their implications for representations, which the author argues should include fine phonetic detail.

Boersma, Paul and Silke Hamann, eds. 2009. *Phonology in perception. Phonology and phonetics volume 15*. Berlin: Mouton de Gruyter.
>   Edited volume with contributions on relationships between phonology and perception. Addresses the nature of phonological representation, focusing on the role of comprehension, and offering several different approaches to modeling phonology that integrate both comprehension and production. Introduction includes a careful review of previous models.

Flemming, Edward. 2005. "Speech perception in phonology." in *The handbook of speech perception*. Edited by David B. Pisoni and Robert E. Remez, 156–182. Malden, MA & Oxford: Blackwell.
>   Reviews key evidence for perception's effects in phonology, focusing on maximization of contrast and position-specific patterns of neutralization, including experimental work documenting these effects. Discusses various approaches to the integration of perceptual effects within an optimality theoretic constraint based approach.

Hawkins, Sarah. 2003. Roles and representations of systematic fine phonetic detail in speech understanding. *Journal of Phonetics* 31: 373-405.
>   Argues that mental representations relevant to speech perception encode multiple types of simultaneously available information, from traditional linguistic structure to fine phonetic detail, gesture and social context. Representational levels informing perception vary with communicative situation, contrasting with left-to right phoneme biased processing commonly assumed in much work on perception.

Hume, Elizabeth V. and Keith Johnson, eds. 2001. *The Role of Speech Perception in Phonology*. San Diego: Academic Press.
>   A rich treatment of perceptual influences on phonological systems, including perceptual compensation for coarticulation, the role of contrast similarity/confusion, and dispersion of contrasting units within available perceptual space. Also highlights the role of redundant cues, abstract linguistic symbolic elements, and phonetically arbitrary grammatical principles. Editors provide detailed introductory chapter (pp. 3-26).

Martin, Andrew and Sharon Peperkamp. 2011. Speech perception and phonology. In *The Blackwell companion to phonology,* 5 Vols. Edited by Marc van Oostendorp, Colin J. Ewen, Elizabeth V. Hume and Keren Rice, 2334-2356. Oxford: Wiley-Blackwell.
>   Excellent overview of complementary influences of perception and phonology on each other. Discusses phonological influences on perception seen through language specific effects in language acquisition and non-native effects in loan phonology. Presents evidence and discusses possible mechanisms of perceptual influences on phonology including role of contrast and sources of misperception.

Nguyen, Noel. 2012. "Representations of speech sound patterns in the speaker's brain: Insights from perception studies", in *Handbook of laboratory phonology*. Edited by Abigail C. Cohn, Cécile Fougeron, and Marie K. Huffman, 359-368. Oxford: Oxford University Press.
>   Reviews research on speech perception in support of both detailed exemplars and phonological abstraction as elements of the representations used in speech perception. Also argues for attention to phonetic detail above the level of the word, including phrasal and discourse influenced phonetic variation.

Steriade, Donca. 2001/2009. "The phonology of perceptibility effects: The P-map and its consequences for constraint organization." In *The nature of the word*. Edited by Kristin Hanson and Sharon Inkelas, 151-179. Cambridge: MIT Press, originally circulated in 2001.
> Documents the strong relationship between perceived similarity and the choice of phonotactically motivated phonological modifications of place and voice assimilation, voice neutralization and epenthesis. Argues that knowledge of phonetic similarity/confusability of contrasts directly determines relative rankings of phonological constraints governing correspondence.

Division of Labor

A perennial issue is the *division of labor* between phonology and phonetics and the nature of the boundary. This is a complex matter that involves both empirical and theoretical questions. Anderson 1985 provides a historical overview of the relationship between phonology and phonetics from the beginning of the 20th Century, laying the groundwork for understanding a number of ongoing debates. Three central questions are widely discussed: (1) whether the phenomena of phonology and phonetics are distinct. One recurrent theme here is the view that phonological patterns are categorical, while phonetic patterns are gradient. (2) Whether phonological and phonetic representations are distinct, and related to this (3) whether the mechanisms (rules, constraints, gestural organization) are distinct. These questions in turn relate to the nature of speaker knowledge and the relationship between the cognitive and physiological dimensions of speech. To address these issues, we divide the discussion into three sub topics: (1) the placement of the boundary including a historical perspective on the division of labor and the mechanisms involved, (2) the nature of phonological and phonetic representations, (3) the primitives of phonology vs. phonetics, reviewing distinctive feature theory and other views of the primitives. The topics here complement the discussion in *Approaches to the interface* as the specific approaches discussed there are dependent in part on the understanding of the division of labor between phonology and phonetics.

Anderson, Stephen R. 1985*. Phonology in the twentieth Century: Theories of rules and theories of representations*. Chicago: University of Chicago Press.
> Excellent history of 20th Century phonology including the relationship between phonology and phonetics. Reviews early views in which phonology started to be understood as distinct from phonetics. Noteworthy introductions to work of Sapir, Trubetzkoy, Jakobson, and the Sound Pattern of English, including tenets of generative phonology such as strict modularity.

The "Boundary" Between Phonology and Phonetics

An understanding of the relationship between phonology and phonetics and the nature of the interface(s) is dependent on an understanding of the boundary between the two domains. In the strictly modular view developed in Chomksy and Halle 1968 (see *Distinctive Feature Theory and Primitives of Phonological Sound Structure*), phonology is understood to be language specific and phonetics is universal. Other views suggest that phonology and phonetics are distinct but best characterized by a more porous boundary. Yet others claim that phonology and phonetics are one and the same. A number of the survey articles touch on this question. See in particular Scobbie 2007 (*Introductions to the interface *) which argues that they are distinct, but that the boundary is very permeable and Ohala 2010 (*Introductions to the interface *) which suggests that the dichotomy is a false one. Ramchand and Reiss 2007 includes the phonology-phonetics interface as one of the key domains of linguistics, presenting two quite different views of this interface. Work in the 1980s argued for an enriched understanding of the role of phonetics based on extensive evidence of language specific phonetic patterns. Kingston and Diehl 1994 introduces the term *phonetic knowledge*, highlighting the cognitive nature of phonetics. This in turn led to much

discussion about the nature of the boundary and whether the phenomena and the mechanisms of phonology and phonetics are distinct. Keating's 1985 seminal paper argued that language-specific phonetic knowledge is part of the linguistic grammar. Pierrehumbert 1990 (cited under *Phonological and Phonetic Representations*) argues that the representations and mechanisms are distinct. Ladefoged 1988 argues that the boundary depends in part on the task at hand. Cohn 2007 (cited under *Introductions to the Interface *) argues that phonology is more categorical and phonetics more gradient, but that the division is porous. Cohn 2006 and Ernestus 2011 both revisit a number of the issues surrounding gradience and categoriality in phonology.   Further attention to the cognitive vs. physiological dimensions is provided in Hoole et al. 2012 which argues that speakers converge on articulations that capitalize on the physical biases of the motoric system and favor realization of their language's distinctions in an *integrated* way. It is not that some articulator properties are specified by the phonology, and others are added in by the phonetics. Tucker and Warner 2010 discusses phonetic assimilation as well as lexical and syllable structure influences on nasal devoicing in Romanian, arguing against a clear division of phonology and phonetics. Sandler 2006, on the other hand, argues for separate phonological and phonetic representations, on the basis of the fact that there are patterns in sign language that are in no way motivated by properties of the articulators.

Cohn, Abigail C. 2006. "Is there gradient phonology?" in *Gradience in grammar: Generative perspectives*. Edited by Gisbert Fanselow, Caroline Fery, Ralf Vogel and Matthias Schlesewsky, 25-44. Oxford: Oxford University Press.
> Discusses the question of whether there is gradience in phonology and in what ways. Concludes that different facets of phonology, inventories, phonotactics, allophony, and morphophonemics may not be uniform in their behavior. Suggests that the categorical – gradient distinction between phonology and phonetics holds loosely, but not strictly.

Ernestus, Mirjam. 2011. "Gradience and categoricality in phonological theory." In *The Blackwell companion to phonology*. Edited by Marc van Oostendorp, Colin J. Ewen, Elizabeth V. Hume and Keren Rice, 2115-2136. Oxford: Wiley-Blackwell Publishing.
> Revisits equation of phonology as categorical and phonetics as gradient, reviewing experimental work highlighting the murkiness of this distinction and reviewing evidence for gradient phonology. Gradient patterns of phonology suggest enriched representations incorporating temporal information and fine phonetic details. Discusses recent exemplar and hybrid models of phonological representation and processing.

Hoole, Philip, Kühnert, Barbara and Marianne Pouplier. 2012. "System related variation.*"* In *The Oxford handbook of laboratory phonology.* Edited by Abigail C. Cohn, Cécile Fougeron, and Marie K. Huffman,115-130. Oxford: Oxford University Press.
> Suggest that separating physical, system-motivated and phonological, contrast motivated articulatory behaviors is not possible. Argue that tongue movements for velars or pitch perturbations associated with consonant voicing are *planned* only in the abstract sense that they are produced using movements optimizing articulator movements while also enhancing transmission of contrastive information.

Keating, Patricia A. 1985. "Universal phonetics and the organization of grammars." in *Phonetic linguistics: Essays in honor of Peter Ladefoged*. Edited by Victoria Fromkin, 115-132.San Diego: Academic Press.
> Gives a clear explication of the SPE view of the place of phonetics in the grammar. Argues convincingly against this view, through discussion of seemingly phonetically natural phenomena which nonetheless show language specific variation, and therefore cannot be realized

phonetically through operation of an automatic and universal phonetic component.

Kingston, John, and Randy L. Diehl. 1994. Phonetic knowledge. *Language* 70.3: 419–454.
    Detailed account of how voicing contrasts are realized in different contexts and languages. Language specific patterns, sometimes involving the same physical devices used to implement opposite Voice values in different languages, provide support for abstractness of phonological features and the role of language specific phonetic rules in the grammar.

Ladefoged, Peter. 1988. The many interfaces between phonetics and phonology. *UCLA working papers in phonetics* 70, 13-23.
    Argues that the nature of the phonology- phonetics interface depends on the kind of description and analysis being done. Makes this point by characterizing different types of descriptions in featural terms, capturing contrast or more fine-grained details, language-specific or universal, articulatory or auditory, binary or multivalued.

Ramchand, Gillian and Charles Reiss, eds. 2007. *The Oxford Hhndbook of LInguistic interfaces.* Oxford: Oxford University Press.
    Provides an introduction to a range of interfaces between key domains of linguistics. Focuses primarily on interfaces that the editors understand to be internal to the grammar, with the primary goal of delineating the nature of "universal grammar". (See Reiss 2007 and Scobbie 2007 cited under * Introductions to the interface *.)

Sandler, Wendy. 2006. "Phonology, Phonetics, and the Nondominant Hand." In *Papers in laboratory phonology: Varieties of phonological competence*. Edited by Louis Goldstein, D. H. Whalen, and Catherine T. Best, 185-212. Berlin: Mouton-de Gruyter.
    Argues that lexical constraints on the non-dominant hand in ASL, and their violability in sandhi domains, support the abstractness of ASL phonological representations and maintenance of the distinction between phonetics and phonology since ASL shows behaviors not directly derivable from properties of the articulators.

Tucker, Benjamin V. and Natasha Warner. 2010. What it means to be phonetic or phonological: The case of Romanian devoiced nasals. *Phonology* 27:1-36.

    On the basis of acoustic, aerodynamic and ultrasound data, presents an account of word-final nasal devoicing in Romanian. Argues that the process has both phonological and phonetic elements, and that the two cannot be separated. More generally argues for a gradient view of the phenomena attributed to phonology and phonetics.

Phonological and Phonetic Representations

A hallmark of early generative phonology was the view that lexical representations were sparse, including only contrastive information with all redundant information added by rule. Thus contrastive information was stored and allophonic information was implemented by rule. (This distinction becomes less important following the principle of *richness of the base* in Optimality Theory.) As evidence of language specific phonetics grew, the nature of phonetic representations as distinct from phonological ones became an important issue. Seminal in this regard was Beckman 1990, the special *Journal of Phonetics* issue, volume 18 Phonetic Representation, edited by Mary Beckman. Pierrehumbert 1990, a widely cited paper from this volume, argues that the mechanisms of phonology and phonetics are distinct and sets the stage for much further thinking on the topic. Also from this volume, Keating 1990 argues for multiple phonetic

representations. It was still generally assumed that phonological representations were discrete abstract representations, while the phonetic representations included fine details instantiated in time and space, though work in Articulatory Phonology (see *Articulatorily Based Approaches*) eschewed this distinction, arguing for a unified representation. Hamann 2011 provides a review of different views on the relationship between phonological and phonetic representation and their mapping, concluding that they are distinct. Arvaniti 2011 addresses issues of representation with respect to intonational units and prosody more generally. More recently, extensive experimental evidence highlights the conclusion that speakers do access and manipulate fine details of speech in a way that suggests that this information must be stored as well (see *Psycholinguistics and Processing)*. Such evidence has led to much debate and controversy about the nature of phonological, lexical, and phonetic representation. Coleman 2002 critiques the standard generative view of sparse lexical representation, arguing for the inclusion of phonetic detail in lexical representations. Lahiri and Reetz 2010 argues for sparse representations based on evidence from perception. Fowler and Galantuuci 2005, in contrast, makes a case for gestural linguistic representations on grounds of parity between perception and production and general evidence of linkages between perception and production in a variety of human and animal activities. A number of contributions discussed in *Insights from Perception* highlight the role of perceptual information in forming and processing representations. These issues also bear on how phonological representations are learned (discussed in *First language acquisition*).

Arvaniti, Amalia 2011. "The representation of intonation." In *The Blackwell Companion to Phonology*. Edited by Marc van Oostendorp, Colin J. Ewen, Elizabeth V. Hume and Keren Rice. Oxford: Wiley-Blackwell Publishing.
> Address the question of what are the linguistic primitives of intonation, reviewing approaches and models, starting with work of mid 20th century. Lays out empirical and theoretical debates about the nature of phonological and phonetic representations of prosody, while highlighting areas of consensus.

Beckman, Mary E., ed. 1990. Phonetic Representation. *Journal of Phonetics* 18: 297-477.
> Special volume of the *Journal of Phonetics*, offering several different views of the nature of phonetic representations and their relationship to phonological representation as this issue started to become much debated. Excellent collection of seminal papers on the topic.

Coleman, John. 2002. "Phonetic Representations in the Mental Lexicon." In *Phonetics, phonology, and cognition*. Edited by Jacques Durand and Bernard Laks, 96-130. Oxford: Oxford University Press.
> Argues that lexical representations are made up of fine phonetic details and that there is little evidence for abstract phonological representations. Phonological competence makes use of these details together with statistical and semantic knowledge. Reviews and critiques evidence for syllables, feet, segments and features.

Fowler, Carol and Bruno Galantucci. 2005. "The relation of speech perception and speech production". *The handbook of speech perception*. Edited by David B. Pisoni and Robert E. Remez, 633-652. Malden, MA: Blackwell .
> Reviews claims of motor theory, and relevant evidence from speech, human cognition and animal behavior generally. Supports several of motor theory's core claims, while rejecting the notion that relating perception and production requires special speech-specific mechanisms. Proposes abstract articulatory vocal tract movement gestures as the basis of linguistic representations.

Hamann, Silke. 2011. "Phonetics-phonology interface." In *The continuum companion to phonology.* Edited by Nancy Kula, Bert Botma, and Kuniya Nasukawa, 202-224. London/New York: Continuum.
> Useful overview paper, providing succinct review of recurring topics on the interface between phonology and phonetics. Focusing on phonological and phonetic representation (which the author concludes are distinct), reviews different models of the mapping, and introduces the Bidirectional Phonology and Phonetics Model incorporating both production and perception.

Keating, Patricia A. 1990. "Phonetic representation in a generative grammar." *Journal of Phonetics* 18:321-34·
> Working within a phonetic implementation model of phonological realization, argues for three types of phonetic representations, including the detailed representation of the output of the phonology as well as both articulatory and acoustic representations, based on evidence from laryngeal contrasts and their realization.

Lahiri, Aditi, and Henning Reetz. 2010. Distinctive features: Phonological underspecification in representation and processing. *Journal of Phonetics* 38.1: 44–59.
> Considers the nature of lexical and phonological representations based on experimental, phonological and historical evidence. Argues for a model of the lexicon with sparse phonological featural representations, using a three-way matching algorithm for the comprehension of speech based on highly variable acoustic input.

Pierrehumbert, Janet B. 1990. Phonological and phonetic representation. *Journal of Phonetics* 18: 375-94.
> One of the most in-depth discussions of the many differences between phonological and phonetic representations (with the latter construed broadly). Argues for quantitative mental representations of phonetic information and advocates proper attention to contextual effects and the differences between acoustic and articulatory structure.

Distinctive Feature Theory and Primitives of Phonological Sound Structure

A core issue in phonology has been the question of the primitives of speech sounds. Any answer to this question carries with it an implicit or explicit theory of the relationship between phonology and phonetics. In much work on phonology and phonetic implementation, sounds have been assumed to be bundles of distinctive features. The central insight is that phonological representations are best characterized in physical terms, thus relating the abstract classificatory functions of phonology to the articulatory and acoustic systems. Starting with Jakobson et al. 1952/1963, it was widely held that a key aspect of the interface between phonology and phonetics was best captured through a universal distinctive feature theory. Since feature theory was taken to be the mechanism for mapping between phonological and phonetic representations, much attention in the literature on the interface focuses on issues in distinctive feature theory. Jakobson et al. 1952/1963, appealing to Information Theory of the time, defined the contrastive properties of both consonants and vowels with acoustically defined features. Chomsky and Halle 1968 expands this set in various ways, providing articulatory definitions and arguing that features should capture not only contrasts but also natural classes. Within generative phonology, for the later decades of the 20th century it was widely agreed that the primitives of phonology were features, with segments characterized by feature matrices. Two recent volumes exploring the phonetic basis of features and the origin of features are Hallé and Clements' 2010 special issue of *Journal of Phonetics* and Clements and Ridouane's 2011 volume of collected papers. Hall and Mielke 2011 provides an excellent overview and introduction to the extensive literature on distinctive feature theory, including aspects directly relevant to the phonology-phonetics interface. More recent work questions the

universality of features as primitives. In considering the "atoms" of phonological representation, Pouplier 2011 argues that gestures (see *Articulatorily Based Approaches*) provide a more adequate account. Mielke 2008 provides an overview of universal feature theory, reviewing the key arguments, but argues that many phonological groupings are not "natural" (as defined by a conjunction of phonological features). Other views suggest that both features and segments may be epiphenomenal, deriving from generalization over memory traces or "exemplars" (see Johnson 1997 and Silverman 2011 cited under *Integrated Views* for introduction to this alternative view). The rich and complex topic of acquisition of primitives of phonology is taken up in *First Language Acquisition* and *Second Language Learning*.

Chomsky, Noam and Morris Halle. 1968. *The sound pattern of English*. New York: Harper and Row. (SPE)
>   Modeling the phonology of English, presents an introduction to generative phonology (chapters 1, pp. 3-14 and 2, pp. 15-55) and proposes a universal set of 26 binary articulatorily defined distinctive features (chapter 7, pp. 293-329), intended to capture all possible contrasts and common phonological groupings of languages of the world. Basis of most common feature system in use.

Clements, G. Nick, and Rachid Ridouane, eds. 2011. *Where do phonological features come from? Cognitive, physical and developmental bases of distinctive speech categories*. Amsterdam: Johns Benjamins.
>   Offers a range of perspectives on the basis and origin of features, including both views that features are innate and views that they are emergent. Varied set of papers with extensive experimental work from acoustics, perception, production, and acquisition.

Hall, Daniel Currie, and Jeff Mielke. Distinctive Features. 2011. *Oxford Bibliographies[*http://www.oxfordbibliographies.com/]*: Linguistics*.
>   Well organized and comprehensive overview of distinctive features. Covers interface and relationship between phonology and phonetics focusing on representational issues. Includes good list of textbooks and journals that cover phonology and phonetics and to some degree their interface.

Hallé, P. A., and G. Nick Clements, eds. 2010. Special issue: Phonetic bases of distinctive features. *Journal of Phonetics 38.1*.
>   Special issue of *Journal of Phonetics* exploring the phonetic bases for phonological features. Includes empirically rich experimentally based papers addressing the biological basis, issues of variation and processing and cross-linguistic variation in production and perception of features.

Jakobson, Roman, C. Gunnar M. Fant, and Morris Halle. 1952/63. *Preliminaries to speech analysis: The distinctive features and their correlates*. Cambridge, MA: MIT Press.
>   First formal proposal of a universal "distinctive features" system, roughly 12 acoustically defined features describing both consonants and vowels, intended to capture all the phonological contrasts of the languages of the world. Provides theoretical underpinnings of distinctive feature theory as developed in the second half of the 20th century.

Mielke, Jeff. 2008. *The emergence of distinctive features*. Oxford: Oxford University Press.
>   Excellent review and critique of distinctive feature theory, concluding that groupings of phonologically active classes are not necessarily "natural" and arguing against the view that phonological classes are insightfully represented in terms of an innate, universal distinctive

feature system. Provides suggestive new directions for understanding phonological patterns.

Pouplier, Marianne. 2011. The atoms of phonological representations. In *The Blackwell companion to phonology*. Edited by Marc van Oostendorp, Colin J. Ewen, Elizabeth V. Hume, and Keren Rice, 107-129. Oxford: Wiley-Blackwell.

> Discusses the basic units of speech and the relationship between symbolic and physical representations, including where temporal organization fits in with symbolic representations. Argues for gestures as both symbolic and physical representations, capturing contrast and articulatory coordination; also discusses relationship between gestures and syllables (see also *Articulatorily based approaches *).

Phonetic Explanations in Phonology

A central topic in the phonology-phonetics interface is sources of explanation in phonology; that is, how observed phonological patterns are accounted for. This is a controversial area with some assuming the sources of explanation are directly integrated into phonological theory while others argue that any such explanations lie outside of phonology. Some of the explanatory concepts appealed to outside of linguistics proper include explaining sound inventories via properties of biological systems, including self organizing systems, and explaining sound patterns by appealing to general cognitive and/or physical constraints/systems. The role of cognition in understanding phonological systems is also addressed in *Psycholinguistics and Processing*. Discussion of this rich and widely debated topic is divided here into three subsections. First we focus on phonetic explanations of sound inventories. We then review literature on phonetic explanations of phonological patterns more generally. We roughly divide this into explanations understood to fall outside of the synchronic phonology, particularly physiological and perceptual pressures that are argued to shape sound change, and explanations integrating into the formal system of phonology. We also include specific critiques of the latter view. Needless to say, there is overlap across these three subsections in terms of empirical coverage and theoretical stance. The interested reader is encouraged to read all three subsections.

Phonetic Explanations of Sound Inventories

A long-standing area of interest has been characterizing the sound inventories of the languages of the world in a way that explains both attested and unattested patterns and also explains why some inventories are particularly common and others quite rare. Since it is generally agreed that, either directly or indirectly, phonetic mechanisms and constraints play some role in explaining the attested inventories of sounds of the languages of world, this is a key topic in discussions of the phonology-phonetics interface. The goal of characterizing the typology of possible sound inventories is implicit in the creation of the International Phonetic Alphabet in the late 19th century (see International Phonetic Association in *Resources*). One central concern of linguistic phonetics which is closely related to explanation of sound inventories has been development of accurate, comprehensive and empirically-based descriptions of the sounds of the world's languages. Over a 40+ year period the UCLA Phonetics Lab group led in such research. A culmination of much of this work is Ladefoged and Maddieson's 1996 *Sounds of the World's Languages*, which offers a concise phonetic introduction to the sounds of the world's languages. See also UCLA Phonetics Lab Language Archive in *Resources* which makes available audio recordings from over 200 languages. Utilizing a balanced sample of inventories is also critical for understanding typological patterns, the central goal of Maddieson's 1984 creation of UPSID (updated in 1994), which has been the starting point for much research in phonology and phonetics. Maddieson 1984 introduces the database, including the sound inventories, attested segments, and extensive bibliography and provides analysis of key results. Maddieson 2007 further explores a number of these issues. One productive line of research in phonetics has been development of theories to account for segment

inventories. Dispersion Theory, discussed in the early seminal paper Liljencranz and Lindblom 1972, has been very influential, as has Stevens' Quantal Theory, introduced here in Stevens and Keyser 2010 and Iskarous 2012, which reviews several phonetic theories about how the nature of inventories relates to the articulatory: acoustic mapping. A theory addressing inventories and phonological patterns more generally is Enhancement Theory, first presented in Stevens et al. 1986 and further discussed in Stevens and Keyser 2010. Using UPSID (see *Resources*), Clements 2003 compares the role of economy with more phonetically motivated explanations in explaining phonological inventories. See also Kingston 2007 in *Introductions to the Interface* for discussion of phonetic explanations of phonological inventories.

Clements, G. Nick, 2003. Feature economy in sound systems, *Phonology* 20.3: 287-333.
> Investigates the degree to which phonological distinctive feature theory captures the attested cross-linguistic patterns of phonological sound inventories. Building on work of Martinet, argues that an organizing principle of phonological inventories is *economy* which is the tendency to maximize contrast within featurally defined phonological classes.

Iskarous, Khalil. 2012. "Articulatory to acoustic modeling." In The *Oxford handbook of laboratory phonology*. Edited by Abigail C. Cohn, Cécile Fougeron, and Marie K. Huffman, 472-483. Oxford: Oxford University Press.
> Presents a brief review and comparison of four theories that intend to explain common features properties of contrasting sound inventories in the world's languages: Quantal Theory, the Theory of Adaptive Dispersion, Dispersion-Focalization Theory, and the Distinctive Region Model.

Ladefoged, Peter and Ian Maddieson. 1996. *Sounds of the world's languages.* Oxford: Wiley-Blackwell.
> Survey of the phonetic possibilities of the world's languages, aiming to describe the totality of possible speech sounds. Fine details of sound production in a vast array of languages are presented, emphasizing a level of specification often ignored by works focusing on the structure of the phonological system more broadly.

Liljencranz, Johan and Bjorn Lindblom. 1972. Numerical simulation of vowel quality systems: the role of perceptual contrast *Language* 48(4):839-861.
> Original paper proposing maximal perceptual contrast as an explanation for the phonetic structure of vowel systems. Argues strongly for the explanatory role of physical mechanisms available for speech and how they relate to general aspects of cognition and communicative efficiency. A direct contrast to the view in SPE.

Maddieson, Ian. 1984. *Patterns of sounds*. Cambridge: Cambridge University Press.
> An influential survey of sound inventories of 317 languages, intended to provide quantifiable data for the testing of hypotheses about phonological typology, such as the relative commonness of different sounds, and patterns of sound co-occurrence that bear on proposed articulatory or acoustic explanations of sound inventories.

Maddieson, Ian. 2007. "Issues of phonological complexity: Statistical analysis of the relationship between syllable structures, segment inventories, and tone contrasts." In *Experimental approaches to phonology*. Edited by Marie-Josep Solé, Patrice Beddor and Manjari Ohala, 93-103. Oxford: Oxford University Press.
> Demonstrates how a large database of phonological inventories can be used to test functional explanations of sound structure. Argues that there is little evidence that languages compensate for complexity in one aspect of their phonology with less complexity in another aspect.

Stevens, Kenneth and Samuel Jay Keyser. 2010. Quantal theory, enhancement, and overlap. *Journal of Phonetics* 38: 10-19.

> This recent summary paper outlines the basic premises of quantal theory, enhancement (described in gestural rather than featural terms, unlike early versions of the theory) and discusses how gestural overlap threatens contrasts supported by quantal and enhancement effects. Supports a strict, traditional separation of phonological representation and phonetic implementation.

Stevens, Kenneth, Samuel Jay Keyser, and Haruko Kawasaki. 1986. "Toward a phonetic and phonological theory of redundant features." In *Invariance and variability in speech processes*, Edited by Joseph S. Perkell and Dennis H. Klatt, 426-49. Hillsdale, NJ: Lawrence Erlbaum Associates.

> Early presentation of feature enhancement theory, in which it is argued that perceptual or articulatory enhancement could motivate featural additions/specifications, at a time when underlying representations were assumed to allow for underspecification. The majority of enhancement examples usually discussed in the literature are presented here.

Phonetic Explanations of Phonological Patterns

It has long been observed that amidst the wide diversity of language differences, there are also many strikingly common sound patterns such as phonotactic constraints and allophonic rules. It is often assumed that many or all of these have a phonetic motivation. Furthermore, comparison across related languages suggests that there are many similar historical changes that have arisen independently, suggesting a possible basis in the perceptual or production machinery shared by humans. Thus, much work concerned with phonetic explanations of phonological structure is also concerned with sound change across time. This is reflected in the papers discussed here, many of which include discussion of historical sound changes. These papers discuss factors such as the possible roles of articulatory preferences, speech effort, and perceptual influences on phonological patterns and sound change. Ohala 1983 is a much cited and influential early paper which proposes the idea that the influence of phonetics via historical change is motivated in large part by misperception of potentially ambiguous phonetic information. Beddor 2009 develops related ideas in depth, focusing on coarticulated nasalization, aiming to clarify with more precision which contexts and conditions are likely to lead to listener-driven sound change. Guion 1988 makes the case for perceptual influence in development of the very common palatalization of velars. Kim 2001 discusses the source of stop assibilation in fine phonetic detail of variants conditioned by vowel context. Hombert et al. 1979 is a classic reference on the development of tone in languages. Westbury and Keating 1986 discusses how aerodynamic conditions favor certain stop voicing patterns over others, another demonstration of the benefits of explicit articulatory (and aerodynamic) modeling. Browman and Goldstein 1990 emphasizes articulatory explanations for common connected speech patterns and consonant allophones. This work, including an account of vowel epenthesis and deletion, is a key inspiration for much subsequent work on epenthetic vowels in first and second language research (See for example Davidson 2011a in *Second language learning*). Kohler 1990 provides historical context for what he sees as the long standing reluctance in the field to consider phonetic explanations for speech properties and discusses the interplay of articulatory and perceptual considerations in conditioning connected speech rules in German. Social factors are also mentioned by Kohler 1990 but not discussed in depth. See also *Sociolinguistic Insights* for further discussion. For more discussion of the influence of perceptual factors, see also *Insights from Perception*.

Beddor, Patrice S. 2009. A coarticulatory path to sound change. *Language* 85:4, 785-821.

Advances theorizing on phonetic sources of sound patterns and changes through detailed acoustic analysis of VNC sequences as well as perception experiments evaluating the role of durational patterns and durational variability in favoring listener reinterpretation of coarticulatory nasalization as a property of the vowel.

Browman, C. P., & Goldstein, L. 1990. Gestural specification using dynamically-defined articulatory structures. *Journal of Phonetics*, 18, 299-320.

Presents the elements of an Articulatory Phonology view of sound representation, with a detailed case study of how such representations can account for apparent vowel deletion and epenthesis cases traditionally described with segmental phonological rules. Support is offered from perceptual experiments of speech generated with the gestural model.

Guion, Susan. 1998. The role of perception in the sound change of velar palatalization. *Phonetica*, 55: 18-52.

Presents data from spectral analysis and perception experiments establishing the perceptual confusability of velar stops and palatal affricates before [i], providing support for a phonetic explanation of the common palatalization of velars before high front vowels. Perceptual data also predict with the relatively frequency of [k] palatalization over [g] palatalization.

Hombert, Jean-Marie, Ohala, John J. and William Ewan. 1979. Phonetic explanations for the development of tones. *Language* 55: 37 – 58.

Argues for physical sources for independent instances of the development of linguistically meaningful tone in languages. Reviews evidence available at the time about the role of factors such as aerodynamics, laryngeal tension and articulator interactions in producing the ambiguous signals that listener's might reinterpret as tone rather than contextual consonantal effects.

Kim, Hyunsoon. 2001. A phonetically based account of phonological stop assibilation. *Phonology* 18: 81-108.

Proposes a phonetic explanation for assibilation of oral stops before high vowels and vocoids. Reviews x-ray and aerodynamic evidence, supplemented with acoustic measures of stop release properties in Korean. Proposes a phonological account of how contextually produced long duration turbulence becomes represented as a fricative componentof a stop.

Kohler, Klaus. 1990. "Segmental reduction in connected speech in German: phonological facts and phonetic explanations." In *Speech production and speech modelling*. Edited by William Hardcastle and Alain Marchal, 69-93. Dordrecht, The Netherlands: Kluwer Academic Publishers.

Reviews sound modifications occurring in connected speech in German, discussing types of articulatory adjustments that could lead to these changes, providing substance to the oft used but under analyzed term *articulatory effort*. An early exposition of the fine phonetic detail often missed by investigations biased by segmental and/or transcriptional methodologies.

Ohala, John J. 1983. "The origin of sound patterns in vocal tract constraints." In *The production of speech*. Edited by Peter F. MacNeilage, 189-216. New York: Springer-Verlag.

An influential and frequently cited paper describing how common cross-language patterns in sound inventories and/or allophony have a basis in properties of the speech mechanism. Examples emphasize aerodynamic consequences, with many examples involving voicing.

Westbury, John and Patricia. A. Keating. 1986. On the naturalness of stop consonant voicing, *Journal of Linguistics* 22, 145-166.
> Employs a circuit model of the vocal tract to examine aerodynamic consequences of different assumptions about articulator tension, position and air pressure and flow settings. Argues that reasonable default settings explain many common patterns in stop voicing. Demonstrates how articulatory modeling can identify which patterns require a non-articulatory explanation.

Integration of Phonetic Influences in Phonology

Still controversial is the issue of where phonetic explanations of sound patterns fit within the linguistic system. Growing out of the work of Chomsky and Halle 1968 (see *Distinctive Feature Theory and Primitives of Phonological Sound Structure*) is the idea that phonologically active sound groupings are "natural" in the sense that they are motivated by phonetic mechanisms, often assumed to be accounted for by markedness. While Chomsky and Halle 1968 attempts to offer an account through a formal theory of markedness laid out in chapter 9 (pp. 400-435), this remains a problematic area, since there is little consensus as to what constitutes an adequate theory of markedness. For many phonologists, sources of explanation of phonological structure is the key issue in understanding the phonology-phonetics interface. (Depending on the proposed answer, this may or may not be part of the interface in a strict sense, but this certainly bears on the issue of the relationship between phonology and phonetics.) The many possible explanations of observed patterns include cognitive and physical constraints, which might directly or indirectly influence phonological systems. At the heart of the controversy is how strong such influences are, and whether they hold on the synchronic grammar or influence the grammar through language change. Here we review approaches that integrate explanations into phonological theory, as well as work that directly critiques this view. Anderson 1981 frames these questions in a classic paper suggesting that there are systematic parts of phonology that are not accounted for by phonetics and other factors external to the phonological system. The view that phonology is directly constrained by phonetics is labeled *grounded phonology* in Archangeli and Pulleyblank 1994. The idea of grounded phonology is central to the interaction of markedness and faithfulness constraints in Optimality Theory, as made explicit in Grounded Optimality Theory (see Hayes et al. 2004 in *Integrated Views*). Hale and Reiss 2000 critiques this approach, arguing that phonology is a computational system and physical explanations lie outside the system. Also much debated is whether phonetic influences on the phonological system impinge on the synchronic system, or play a role only indirectly through historical change. For a number of papers taking this latter approach, see *Phonetic Explanations of Phonological Patterns*. Blevins 2006 incorporates this view as one of several possible explanations. Hyman 2001, extending some of the themes in Anderson 1981, argues that there are systematic aspects of phonology that are not "natural", while Hayes and Steriade 2004 develops the view that phonetic influence is direct and synchronic through phonetic knowledge. More recent work addresses the relative contributions of the cognitive and physical systems as well as the role of distributional data, exemplified in Moreten 2008.

Anderson, Stephen R. 1981. Why phonology isn't 'natural. *Linguistic Inquiry* 12: 493-539.
> In this classic paper, Anderson raises the question of the sources of naturalness in phonology, concluding that phonology is not simply a reflection of extralinguistic systems and that effects from the latter are indirect, mediated by the grammar.

Archangeli, Diana, and Douglas Pulleyblank. 1994. *Grounded phonology*. Cambridge, MA: The MIT Press.
> Argues that phonology is "grounded" in the sense that it is shaped by phonetic constraints on production and perception. Taking cross-linguistic patterns of vowel harmony as a case study,

argues that observed constraints hold asymmetrically in a manner consistent with expected phonetic constraints.

Blevins, Juliette. 2006. A theoretical synopsis of evolutionary phonology. *Theoretical Linguistics* 32.2: 117-166.
> Introduces Evolutionary Phonology, which embodies the somewhat controversial proposal that constraints on phonology lie outside the grammar, proposing a typology of explanations including "change", "chance" and "choice" to account for patterns many phonologist argue are accounted for in the synchronic grammar.

Hale, Mark, and Charles Reiss. 2000. "Phonology as cognition." In *Phonological knowledge: Conceptual and empirical Issues.* Edited by Noel Burton-Roberts, Philip Carr, and Gerard Docherty, 161–184. New York: Oxford University Press.
> Drawing a distinction between form and substance, assumes a sharp division between phonology as a formal computational system and phonetics as functional. Argues that individual speakers can't know typologies of markedness assumed in Optimality Theoretic approaches, but must be able to learn these patterns from simple cognitive mechanisms.

Hayes, Bruce, and Donca Steriade. 2004. "Introduction: The phonetic bases of phonological markedness." In *Phonetically based phonology*. Edited by Bruce Hayes, Robert Kirchner, and Donca Steriade, 1–33. Cambridge, UK, and New York: Cambridge University Press.
> Argues for a middle ground between explanations within the phonology and those that are extragrammatical, with the link between phonological systems and phonetic grounding due to phonetic knowledge that is learned anew by each individual.

Hyman, Larry. 2001. "On the limits of phonetic determinism in phonology: *NC revisited." In *The role of speech perception phenomena in phonology*. Edited by Elizabeth V. Hume and Keith Johnson, 141-185. San Diego: Academic Press.
> Presents counterexamples to claims of the universality of voicing of obstruents after nasals and related claimed implicational universals, showing that these counterexamples are nevertheless systematic and part of the synchronic phonology. Argues that phonological systems cannot be directly constrained by phonetic mechanisms.

Moreton, Elliott 2008. Analytic bias and phonological typology. *Phonology* 25(1):83--127.
> Investigates biases in the phonological system contributing to the development of an adult phonological system. Interprets innateness in terms of cognitive biases and suggests that both analytic bias and cognitive bias together with distributional information shape learning of possible phonological systems.

Relationship More Broadly Defined

In recent years, the study of sound structure has expanded well beyond the more canonical definitions of phonology and phonetics. In several academic areas, growing bodies of research are examining in depth what are traditionally thought of as phonology and phonetics. These include (1) sociolinguistic insights, (2) psycholinguistics and processing of sound structure, (3) first language acquisition and (4) second language learning of both phonology and phonetics. Here we focus on the relationship between phonology and phonetics as it is understood within the broader context of each of these fields. We do not attempt to offer a more general introduction to these areas, though some of the works cited provide broader framing of these fields.

Sociolinguistic Insights

The variability of spoken language has been at the core of much theoretical debate about the nature of linguistic representations and the boundary between linguistic and non-linguistic knowledge relevant to the acts of speech production and perception. Thus, variation is treated, directly or indirectly, in almost everything discussed here. In this section, however, the focus is on work discussing linguistic representations as they relate to social dimensions of speech, addressing variable data directly in light of discussions about what constitutes phonology and phonetics. Much recent work has focussed on sound variability due to subject differences defined in terms of social groupings Variability derived from physical characteristics, speech style or emotional states is not included here. Two main issues tie together work in this area. First, any property of language that can be manipulated socially must be definable in structural terms, which in turn tells us what types of structure can be learned. Second, social structure and interaction is an integral part of the process of the development and maintenance of phonological categories and representations. Labov 2007 is a deeply elaborated discussion of how the grammars of individuals and communities change and of the role of speaker age and linguistic history on the course and form of that change. Foulkes and Docherty 2006 emphasizes the rich and subtle nature of the very fine phonetic details which correlate with social differences, arguing that this knowledge is best characterized with episodic representations as advocated in exemplar approaches. Warren et al. 2007 demonstrates how social information affects listener expectations, and discusses possible implications for how phonetic variability is processed during word recognition. Pierrehumbert 2006 argues for social interaction as a core factor motivating the existence and stability of phonological systems. Munson 2010 discusses ways that people learn socially relevant phonetic information and proposes a possible model of how this information is represented cognitively. Recent work has also started to address the acquisition of phonetic variation. Two excellent introductions are Pierrehumbert 2003 and Foulkes 2010. Pierrehumbert 2003 emphasizes the role of fine phonetic details and variation as integral to the learning of more abstract representations. Foulkes 2010 reviews theories of how phonetic and phonological cues to socio-indexical information are learned.

Foulkes, Paul. 2010. Exploring social-indexical variation: A long past but a short history *Laboratory Phonology* 1, 5-39.
> Discusses evidence for exemplar representations of socal-indexical information and the relation of these to more traditional linguistic representations within the context of early language acquisition. Reviews predictions exemplar based theories make for the course of acquisition, citing support from acquisition studies and identifying promising directions for future research.

Foulkes, Paul and Gerard Docherty. 2006. The social life of phonetics and phonology. *Journal of Phonetics* 34(4), 409-438.
> Describes how social patterning is reflected in systematic fine phonetic details in varieties of English, arguing for exemplar type representations as a means of handling variability in pronunciation of the same word in different social situations as well as over time. Outlines important areas of future research in sociophonetics.

Labov, William. 2007. Transmission and diffusion. *Language* 83:344-387.
> Provides an account of the two commonly identified modes of sound change spread— transmission and diffusion. A key factor identified in language change is the age of the language learner and the consequences for their ability to learn the full set of structural conditions for occurrence of a particular variant.

Munson, Benjamin. 2010. Levels of phonological abstraction and knowledge of socially motivated speech-sound variation: A review, a proposal, and a commentary on the papers by Clopper, Pierrehumbert, and Tamati; Drager; Foulkes; Mack: and Smith, Hall, and Munson. *Journal of Laboratory Phonology* 1: 157-177.
> Discusses the complexity of the relationship between phonetic properties of speech and their social and semantic meanings. Reviews 5 LabPhon papers on sociophonetics and proposes a model of how sociophonetic information might be represented cognitively, including episodic representations linked to more abstract higher level phonological and socio-indexical representations. Also identifies promising areas of future research.

Pierrehumbert, Janet B. 2003. Phonetic diversity, statistical learning, and acquisition of phonology. *Language and Speech* 46: 115-154.
> Addresses complexities of phonological acquisition in the face of rich phonetic and sociolinguistic variation. Discusses how categories can be learned by the infant based on this rich variable input. Uses exemplar theory to model bottom-up learning, supported by the speech community's perception-production loop.

Pierrehumbert, Janet B. 2006. The next toolkit. *Journal of Phonetics* 34: 516-530.
> Argues that social interaction is a critical factor contributing to stable phonological systems. Reviews linguistic evidence for exemplar representations and for phonological categories, arguing for hybrid models of linguistic representation, with multiple levels of representation and mechanisms for statistical learning and situational indexing, and phonological generalization over stored exemplars.

Warren, Paul, Jennifer Hay and Bryn Thomas. 2007. "The loci of sound change effects in recognition and perception." In *Laboratory Phonology 9.* Edited by Jennifer Cole and Jose Ignacio Hualde, 87-112. New York: Mouton de Gruyter.
> Discusses effects of speaker age on listener bias in perception of vowels in a community where a merger is in progress. Argues for an exemplar model which includes a prelexical processor with its own internal structure that governs access to lexical items represented as exemplars.

Psycholinguistics and Processing

Starting from early generative theory (see Chomsky and Halle 1968 * Distinctive Feature Theory and Primitives of Phonological Sound Structure*) there has been interest in the cognitive aspects of sound structure and attempts to understand the contributions of the phonological linguistic system as it relates to both the cognitive system more generally and the physical system of sound production and perception. Goldrick 2011 provides an excellent discussion of these issues, serving as an accessible starting point for this complex topic. Until recently the role of cognition in understanding sound systems and patterns was studied in psycholinguistics behaviorally. More recently, brain imaging results are also being used to investigate these issues. Contributions in Gaskell and Zwitserlood 2011 focusing on the nature of lexical representations provide an introduction to both more traditional and newer methodological approaches in psycholinguistics and neurolinguistics. Schiller and Meyer 2003 reviews psycholinguistic evidence on whether production and perception access identical representations. McMurray and Farris-Trimble 2012 argues that perception and production need *not* reference identical representations, but that the nature of speech favors development of parsimonious representations. See Fowler and Galantucci 2005 in *Phonological and Phonetic Representations* for a differing view. Ernestus and Baayen 2007 discusses how relationships in the lexicon affect perception of words and specifically phonological contrasts occurring in different patterns for different groups of morphologically related words. Kraljic and Samuel

2006 shows that lexically mediated exposure to phonetic variability can shift a phonemic category boundary and that listeners can generalize this effect to sounds sharing phonological properties with the training stimuli. Cutler et al. 2010 fleshes out the consequences of both speaker-related variation and our ability to ignore it, for our understanding of the nature of mental representations relevant to speech. While much recent research has provided evidence for episodic representations, supporting an exemplar view (see "Integrated Views*). Cutler et al. argue against the practice in much recent work of taking episodic representations as equivalent to lexical representations (see also Munson 2010 *Sociolinguistic Insights*). Kingston 2005 reviews evidence for autonomous pre-linguistic processing of speech based on perceptual integration of acoustic cues. Perceptual integration forms the cognitive basis for abstraction of feature values over multiple acoustic cues, for which [voice] has been the most consistent example in psycholinguistic work (e.g., Kraljic and Samuel 2006). Further work of this type could help explain the behavior of other phonological properties, both their online perception and their behavior in linguistic systems over time (see also, e.g., Warren et al. 2007 cited under *Sociolinguistic Insights*). Keating and Shattuck-Hufnagel 2002 addresses the issue of speech encoding as it integrates prosodic and segmental information.   See also Fujimura in *Phonetic Representaiton of Segmental Structure*.

Cutler, Ann, Eisner, Frank, McQueen, James and Dennis Norris. 2010. How abstract phonemic categories are necessary for coping with speaker-related variation. In *Laboratory phonology 10*. Edited by Cecile Fougeron, Barbara Kühnert, Mariapaola D'Imperio, and Nathalie Vallée, 91-111. Berlin: de Gruyter.
> Argues for a hybrid view of speech processing in which exemplar effects are non-lexical and abstract categorical effects are invoked in a pre-lexical processor. Speaker-specific information is stored outside the lexicon but is available to a prelexical processor that generalizes over variable inputs accounting for normalization and perceptual learning.

Ernestus, Mirjam, and Harald Baayen. 2007. Paradigmatic effects in auditory word recognition: The case of alternating voice in Dutch. *Language and Cognitive Processes*, 22(1), 1-24.
> Lexical decision experiments on subphonemic nonneutralized cues to voicing contrasts in German stem final obstruents show that the number of other members of the paradigm with voiced final obstruents affected lexical response time. Argues for exemplar models with separate "entries" for both morphologically simple and complex forms.

Gaskell, Gareth and Pienie Zwitserlood, eds. 2011. *Lexical representations*. Berlin: De Gruyter Mouton.
> Interdisciplinary volume on lexical representations, with contributions by linguists, psycholinguists, and neurolinguists. Provides empirically rich introduction to the complex set of issues involved in understanding the nature of lexical representation, and the processing of speech.

Goldrick, Matthew. 2011. "Using psychological realism to advance phonological theory." In *Handbook of phonological theory, 2nd edition*. Edited by John Goldsmith, Jason Riggle, and Alan C. L. Yu, 631-660. Wiley-Blackwell.
> Accessible and clear introduction to psychological approaches to understanding phonology. Reviews psycholinguistic models, addresses why such approaches are critical for phonological theory, and shows how psychological realism provides insight into phonological problems, taking knowledge of phonotactic well-formedness as a case study.

Keating, Patricia A. and Stephanie Shattuck-Hufnagel. 2002. "A prosodic view of word form encoding for speech production", UCLA Working Papers in Phonetics #101, August 2002, pp. 112-156.

Reviews earlier approaches to speech encoding as understood in terms of phonological encoding and phonetic encoding. Addresses role of prosodic structure, providing evidence for integration of prosodic information in phonological encoding, arguing for what they term a *prosody first model*.

Kingston, John. 2005. "Ears to categories: New arguments for autonomy." In *Prosodies: Proceedings of the first conference on phonetics and phonology in Iberia (PaPI),* Edited by Sonia Frota, Marina Vigario, and Maria João Freitas, 177-222. Berlin: Mouton de Gruyter.
    Detailed review of evidence for auditory integration of acoustic cues, taking voicing contrasts as a case study. Reviews differences between auditory and linguistically based contextual perception effects and emphasizes the importance of distinguishing between categorization and discrimination. Argues that auditory integration is independent from perceptual processes accessing linguistic knowledge.

Kraljic, Tanja and Arthur Samuel. 2006. Generalization in perceptual learning for speech. *Psychonomic Bulletin and Review*, *13*(2), 262-268.
    Perceptual learning study demonstrating that shifted VOT values for coronal stop voicing contrast generalize to contrast for labials despite labials having different specific contrasting values. Evidence for abstract feature Voice, phonetic specifics of which can be changed in real time by experience with effects on long term storage of values.

McMurray, Bob and Ashley Farris-Trimble. 2012. "Emergent information level coupling between perception and production." In *Oxford handbook of laboratory phonology*. Edited by Abigail C. Cohn, Cécile Fougeron, and Marie K. Huffman, 369-395. Oxford: Oxford University Press.
    Argues that coupling between perception and production is not a design feature of language necessitating representations using identical units. Rather, coupling emerges because there are statistical tendencies which the perceptual system becomes attuned to by computing probability distributions over data for multiple types and sizes of units.

Schiller, Niels and Antje Meyer, eds. 2003. *Phonetics and phonology in language comprehension and production. Differences and Similarities*. Berlin, New York: Mouton de Gruyter.
    A collection of papers addressing the question of whether the representations employed in speech production and perception are the same, employing evidence primarily from psycholinguistic research.

First Language Acquisition

A key area of inquiry for the understanding of sound structure is acquisition. In early generative theory, typological patterns of grammar were assumed to be closely tied to the mechanisms of acquisition, leading to specific conclusions of innate language structures to account for universal or widely attested cross-linguistic patterns. As more sophisticated experimental methods have been developed to study the perception, production, and understanding of speech by infants and small children, a much richer picture has emerged of the acquisition of both phonetics and phonology and how these relate in turn to the acquisition of the lexicon and other aspects of linguistic grammar. Some approaches to acquisition assume that patterns and mechanisms of first language acquisition and second language learning are one and the same, while others assume they are distinct. Ultimately this is an empirical question. In this section we introduce some key literature on the acquisition of phonetics and phonology by infants and toddlers. Gerken 2009, in a general introduction to language acquisition devotes considerable attention to the acquisition of phonetics and phonology. Munson et al. 2012 and Demuth 2011 provide accessible and

informative reviews of issues as currently understood and recent empirical results in the acquisition of sound structure. Vihman and Velleman 2000 highlights the role of both phonetics and phonology in any adequate account. Menn and Vihman 2011 review the issues of acquisition of features, arguing that assumptions of innate distinctive features is not necessary. While Cristià, Seidl, and Francis 2011 provides an excellent review of empirical results and ingredients of an adequate account of the acquisition of phonological primitives. Kuhl 2009 and Werker 2012 both provide detailed review of extensive recent experimental work on development of perception in infants, both monolingual and bilingual. See *Second Language Learning* for a review of recent work on second language learning, particularly as it bears on the relationship between phonology and phonetics. Recent work has started to address the issue of acquisition of socioi-indexial properties of language. See Pierrehumbert 2003 and Foulkes 2010 in *Sociolinguistic Insights*. The growing body of research on grammar induction as evidenced by artificial grammar learning is not addressed here, except to the degree that it addresses the relationship between phonology and phonetics. See Cristia and Seidle 2011 and Moreton 2008 (*Integration of Phonetic Influences in Phonology*) for review of relevant literature.

Cristià, Alejandrina, Seidl, Amanda, and Alexander L. Francis 2011. "Phonological features in child infancy." In *Where do phonological features come from? Cognitive, physical and developmental bases of distinctive speech categories*. Edited by G. Nick Clements and Rachid Ridouane, 303-326. Amsterdam: Johns Benjamins. Pp. 261-301.
> Provides review of recent experimental work on acquisition of features by infants and toddlers, explaining both the experimental paradigms used and models proposed. Argues for a separation of the distinctive and classificatory function of features.

Demuth, Katherine 2011. "The acquisition of phonology." In The handbook of phonological theory. Edited by John Goldsmith, Jason Riggle, and Alan Yu, 571-595. Malden, MA: Blackwell.
> Comprehensive review of the development of the field of acquisition of phonology including key empirical results. After a historical review of early work, discusses recent developments, including constraint based approaches, new longitudinal data and experimental approaches in related fields of acquisition of both segmental phonology and prosody.

Gerken, LouAnn. 2009. *Language Development*. San Diego: Plural Publishing Inc.
> Introduction to language acquisition, focusing primarily on first language acquisition. Addresses acquisition of sound system, word structure, and sentence structure, providing an excellent introduction to acquisition of phonology from the perspectives of both production and perception, reviewing both empirical issues and theoretical debates.

Kuhl, Patricia K. 2009. Early language acquisition: Phonetic and word learning, neural substrates, and a theoretical model. *The Perception of Speech: From Sound to Meaning*. Editied by Brian C. J. Moore, Lorraine K. Tyler and William Marslen-Wilson. 103-131. Oxford, UK: Oxford University Press.
> Reviews recent advances in the study of early acquisition of sounds, introduces current neurolinguistic methodology used in infants studies which help provide a picture of early acquisition in monolingual and bilingual infants.

Menn, Lise and Marilyn Vihman. 2011. Features in child phonology: Inherent, emergent, or artefacts of analysis? In *Where do phonological features come from? Cognitive, physical and developmental bases of distinctive speech categories*. Edited by G. Nick Clements and Rachid Ridouane, 261-301. Amsterdam: Johns Benjamins.
> Tackles the question of whether distinctive features are innate, reviewing core assumptions going

back to Jakobson's view of the universal patterns of unfolding of phonological contrasts. Argues based on cross-linguistic data that feature acquisition is emergent and does not follow a universal predetermined path.

Munson, Benjamin, Edwards, Jan, and Mary E. Beckman. 2012. "Phonological representations in language acquisition: Climbing the ladder of abstraction." In *The Oxford handbook of laboratory phonology*. Edited by Abigail C. Cohn, Cécile Fougeron, and Marie K. Huffman, 288 - 209. Oxford: Oxford University Press.

> Provides a rich discussion of the development of phonological representations, including review of recent experimental evidence from production, perception, and sociolinguistic indexing. Shows how category learning and development of these categories into abstract representations in a linguistic system are built out of fine grained and detailed input.

Vihman, Marilyn and Shelley Velleman. 2000. "Phonetics and the Origin of Phonology", in *Phonological knowledge: conceptual and empirical Issues.* Edited by Noel Burton-Roberts, Philip Carr, and Gerard J. Docherty, 305-339. Oxford: Oxford University Press.

> Discusses the role of phonology and phonetics in acquisition of a phonological system. Argues that neither phonology nor phonetics alone offers a full account. Both dimensions contribute and need to be integrated into an adequate model. Provides an informative overview of results and issues in the acquisition of phonology.

Second Language Learning

Studies of second language phonology have also provided evidence about the relationship between phonology and phonetics. Traditionally much of this work has been primarily applied in its orientation; however, recently it has been used to address issues central to theoretical linguistics. This work has deepened the understanding of how acquisition of a second phonological system interacts with the first and sheds light on linguistic representation of such systems. Recent reviews in Altman and Kabak 2011 and Davidson 2011b provide excellent introductions to this growing area of the literature. Best 1995 reviews the Direct Realism approach to speech perception (see also Fowler and Galantucci 2005 in *Phonological and Phonetic Representations*) and outlines the Perceptual Assimilation Model of Second language perception and sound representation. MacKay et al. 2001 reviews the Speech Learning Model of second language perception and sound representation and discusses the importance of amount of input for second language production and perception. Bradlow et al. 1999 summarizes and extends important earlier results about the beneficial role of input variation on both perception and production in L2. Best et al. 2011 includes several articles on the influence of first language phonetics and phonology on second language representations and learning. Davidson 2011a discusses ways that second language perception is influenced by first language grammar, drawing attention to differences between loan word and second language phonology.

Altmann, Heidi and Bariş Kabak. 2011 "Second language phonology." In *The continuum companion to phonology.* Edited by Nancy Kula, Bert Botma, and Kuniya Nasukawa, 298-319. London and New York: Continuum [renamed The Bloomsbury Companion to Phonology].

> Reviews research on and acquisition of second language segments, syllable structure, phonotactics, and stress. Emphasizes the importance of perceptual factors in constraining L2 proficiency in production. Argues that the L2 phonological system is not an imperfect imitation of native speech, but rather the "realization of imperfect representations". (P. 318)

Best, Catherine T. 1995. "A direct realist perspective on cross-language speech perception." In Speech perception and linguistic experience: Theoretical and methodological issues in cross-language speech research. Edited by Winifred Strange. 167–200. Timonium, MD: York.

> Provides a review of direct realism approaches to speech perception and speech representations, with explicit comparisons to motor theory and psychoacoustic views. Discusses the basic assumptions and predictions of the Perceptual Assimilation Model of second language sound structure perception and learning.

Best, Catherine T., Bradlow, Ann R., Guion-Anderson, Susan, and Linda Polka. 2011. Using the lens of phonetic experience to resolve phonological forms. Introduction to Special issue on Cross-Language Speech Perception and Variations in Linguistic Experience. *Journal of Phonetics*, 39, 4, 453-456.

> Introduces theoretical and empirical contributions about how perception of phonological forms is affected by the phonetic structure of the speaker's other language(s) as well as influences of general learning mechanisms, and language-specific perceptual tuning mechanisms. Also includes investigations of language learning by simultaneous bilinguals, and later second language learners.

Bradlow, Ann, Akahane-Yamada, Reiko, Pisoni, David, and Yoh'ichi Tohkura. 1999. Training Japanese listeners to identify English /r/ and /l/: Long-term retention of learning in perception and production. *Perception & Psychophysics*, 61:5, 977-985.

> Reports that Japanese speakers trained with English l/r contrast with varied contexts and voices show improved auditory discrimination and improved production. Effect on production is taken to argue for a common mental representation for the two processes. Lack of native-like abilities, however, highlights lasting effects of L1 on phonetic processing.

Davidson, Lisa. 2011a. Phonetic, phonemic, and phonological factors in cross-language discrimination of phonotactic contrasts. *Journal of Experimental Psychology: Human Perception and Performance* 37:1, 270-282.

> Discusses how phonotactic and allophonic factors as well as word length and experiential factors impact second language perception and lexical acquisition. Proposes possible bases for differences between loan word adaptation and second language acquisition.

Davidson, Lisa. 2011b. Phonetic and phonological factors in the second language production of phonemes and phonotactics. *Language and Linguistics Compass* 5:3, 126–139.

> Discusses recent empirical results in second language acquisition of segmental and suprasegmental structure, considering the implications for various theories of second language learning, from Contrastive Analysis and the Markedness Differential Hypothesis to more current accounts in terms of Optimality Theory).

MacKay, Ian R. A., Flege, James Emil, Piske Thorsten, and Carlo Schirru 2001. Category restructuring during second-language (L2) speech acquisition. *Journal of the Acoustical Society of America*, 110, 516-528.

> An example of the large body of work of Flege and colleagues, this paper reports on effects of age of arrival on production and perception of English stops by Italian immigrants. Outlines the Speech Learning Model and attributes age effects in this study to amount of input rather than age per se.