Experimental Methods for Detecting Phonetic Change Over Time: A Comprehensive Survey

Siqi He
Shanghai Jiao Tong University / Shanghai, China
Ruprecht Karl University of Heidelberg / Heidelberg, Germany
hesiqiid@sjtu.edu.cn

Abstract

This paper reviews the experimental methodologies used to detect phonetic change, focusing on historical analysis, contemporary observation, and advanced experimental techniques. By focusing on acoustic analysis, articulatory phonetics, perceptual studies, and computational modelling, the study outlines the mechanisms behind the phonetic change and evaluates the strengths and limitations of present research methodologies. Through the evaluation of diverse datasets, including historical linguistic records and modern speech samples, the importance of varied and robust data in phonetic change research is emphasized. The paper advocates for interdisciplinary approaches and the integration of technology to enhance future research, suggesting that expanding research to include lesser-studied languages and utilizing advancements in machine learning and neuroimaging could provide deeper insights into language evolution. This survey contributes to a better understanding of the experimental phonetics field, suggesting pathways for future research to advance the study of linguistic transformations.

Keywords: Phonetic Change, Diachronic Linguistics, Acoustic Analysis, Articulatory Phonetics, Computational Modeling

1 Background

The study of phonetic change over time combines insights from linguistics, cognitive science, and technology. This research studies the core of diachronic linguistics, analyzing the subtle yet significant shifts in language sounds over centuries. Phonetic change, essential to language evolution, reveals the dynamic interaction between sound systems and linguistic structures, offering a thorough understanding of how languages change and adapt over time. This paper intends to review the experimental methods used in detecting, analyzing, and interpreting phonetic change, relying on extensive linguistic research to map the developmental trajectories of language.

Phonetic Change The phenomenon of phonetic change is exemplified by the Great Vowel Shift, a transformative period in the history of the English language that significantly altered its vowel system between the 15th and 18th centuries (Lass, 1990). This event, thoroughly documented by comparative historical linguistics, represents just one example in the ongoing series of phonetic changes—a phenomenon actively taking place in languages around the world. The Great Vowel Shift exemplifies the kind of phonetic change this paper aims to examine, using experimental methodologies to elucidate these linguistic transformations.

Research Questions Central to this study are several key research questions:

- What experimental methodologies are currently employed to detect phonetic change?
- How do these techniques integrate with both contemporary observations and historical data?
- How do experimental phonetics enrich our understanding of the forces that drive phonetic change?
- What implications do these findings hold for theories of language evolution and practical applications such as language preservation and speech recognition technology?

Methods and Outcomes These inquiries critically assess the methods, outcomes, and data sets supporting experimental studies of phonetic change, examining the design, analysis, and interpretive frameworks employed by researchers. In an

era characterized by rapid technological advancements, this critical perspective is crucial for identifying the strengths and limitations of existing research practices and for emphasizing the potential for future innovations in linguistic research.

Significance Understanding the mechanisms of language evolution has significant implications for language preservation, the development of teaching methodologies, and the enhancement of speech recognition technologies. Moreover, experimental phonetics provides insight into the cognitive processes underlying speech perception and production, offering a glimpse into the fundamental ways humans interact with language.

Structure of the Paper This paper is structured to offer a comprehensive overview of phonetic change research. It begins with a historical overview, emphasizing seminal studies and theoretical models that have shaped the field, such as the foundational work of Labov (1965) and Ohala and Jones (1993). This prepares the ground for an in-depth review of experimental methods, such as acoustic analysis, essential for measuring sound changes (Pierrehumbert, 2001), and articulatory phonetics, which focuses on the physical creation of sounds and their implications for change (Fowler, 1996).

A central aspect of this review is the examination of data sets critical to phonetic change research, sourced from a broad range of historical linguistic records and modern speech samples. This part discusses the difficulties linked with these datasets, like the representativeness of samples and the precision of historical transcriptions (Labov, 1963; Ohala and Jones, 1993). Additionally, it describes effective strategies for tackling these problems, thereby enhancing the accuracy and reliability of research in this area.

Conclusion and Outlook The paper concludes by synthesizing the insights gained from this survey, reflecting on the current state of phonetic change research and proposing directions for future studies. By offering a critical appraisal of experimental methodologies, results, and data sets, this paper contributes to a deeper understanding of language evolution processes. It emphasizes the role of experimental phonetics in analyzing the complex processes driving the continuous transformation of human language, reasserting the significance of phonetic change as a means to examine the living history of language.

In summary, this paper traverses the complex realm of phonetic change research, motivated by a dedication to thoroughness, critical questioning, and the progression of knowledge. By carefully examining experimental methodologies and their impact on our comprehension of language evolution, this review seeks to advance the field of diachronic linguistics, clarifying directions for future research in this vibrant and changing area of study.

2 Related work

In the field of diachronic phonology, several key survey papers have paved the way for a deeper understanding of phonetic change over time, each contributing unique insights into the mechanisms and methodologies for studying these phenomena. However, the literature still has shortcomings, especially in the thorough assessment of experimental methods and their use in grasping phonetic change.

Foundational Studies One foundational paper by Labov et al. (1971) provides an extensive review of sociolinguistic factors influencing sound change, focusing on the social dynamics driving linguistic variation and change. While Labov et al.'s work is seminal in linking social factors with phonetic change, it offers limited discussion on the specific experimental methods used to detect and analyze these changes, leaving room for a more methodologically focused survey.

Another important contribution is made by Ohala and Jones (1993), who studies the role of perceptual and production biases in phonetic change. Ohala and Jones's paper plays a key role in forming theories about the phonetic basis of sound change, focusing mainly on theoretical viewpoints without going into detail about experimental confirmation or the variety of modern methods for examining these biases directly.

Computational Approaches A more recent survey by Pierrehumbert (2003) examines probabilistic phonology and its implications for understanding phonetic change, integrating computational models with empirical data. While this paper advances the discussion by incorporating computational approaches, it still leaves a gap in the comprehensive review of acoustic and articulatory methodologies that have emerged in recent years.

Typological Analysis Hyman and Plank (2018) presents a critical analysis of typological patterns in

phonetic change, offering an important viewpoint on the universal principles and limitations that influence sound change. However, Hyman and Plank's work, while rich in typological analysis, does not extensively cover the experimental methods that can empirically test these typological patterns and hypotheses.

Experimental Evidence Lastly, Sanker (2018) presents a survey of experimental evidence for diachronic change, focusing on patterns of sound change in progress and experimentally induced changes. This paper comes closest to filling the gap in the literature by linking synchronic and diachronic data through experimental methods. Nevertheless, Sanker's survey, while comprehensive, could be expanded to include a broader range of experimental techniques and their applications across diverse linguistic contexts.

The present work aims to address these gaps by offering a detailed and comprehensive survey of experimental methods specifically tailored for detecting phonetic change over time. Unlike previous reviews, this paper focuses on critically assessing the methods, results, and data derived from a variety of experimental approaches, underlining recent progress and identifying areas for future research.

3 Methods

In studying phonetic change over time, various experimental methods have been used to analyze the complex processes behind the changing sounds of languages. This section outlines four main methodological approaches that have greatly enhanced our grasp of phonetic change: Acoustic Analysis, Articulatory Phonetics, Perceptual Studies, and Computational Modeling. Each method provides a unique perspective for examining phonetic change, offering deep insights into the complex aspects of language development (see Table 1).

Acoustic Analysis Acoustic Analysis stands as a cornerstone in the study of phonetic change, offering precise, quantifiable measurements of speech sounds. This approach focuses on the examination of sound waves to discern changes in phonetic features over time, such as formant frequencies, pitch, intensity, and duration. Acoustic analysis enables researchers to monitor changes in specific phonetic features across various languages and dialects, supplying essential data for formulating and verifying theories of sound change.

The application of acoustic analysis in studying phonetic change is exemplified in the work of Fox and Jacewicz (2009), who utilized spectrographic analysis to track vowel shifts in American English dialects. Similarly, Wagner et al. (2021) used acoustic measurements to study how perceptual biases influence the development of phonetic systems, emphasizing the role of acoustic properties in driving sound change. These studies emphasize the significance of acoustic analysis in offering quantifiable, objective data on sound features, aiding in a more thorough comprehension of the processes driving phonetic change.

However, while acoustic analysis offers powerful tools for measuring and analyzing sound change, it is not without limitations. One challenge is the interpretation of acoustic data, as changes in acoustic properties may not always correspond directly to changes in linguistic perception or articulation (Pierrehumbert, 2001). Additionally, the reliance on technological recording and analysis tools means that the quality and comparability of acoustic data can be influenced by the equipment and methodologies used (Hyman, 2001).

Despite these challenges, acoustic analysis remains a vital method in the study of phonetic change, providing a quantitative basis from which further research into the articulatory, perceptual, and computational aspects of sound change can be launched. By carefully measuring and analyzing speech sounds, acoustic analysis keeps clarifying the mechanisms of phonetic change, adding to a thorough comprehension of how language transforms.

Articulatory Phonetics Articulatory Phonetics studies the physiological processes of sound production, offering insights into the mechanisms that may drive phonetic change. This methodological approach utilizes advanced imaging and measuring techniques to observe and analyze the movements and positions of the speech organs during phonation. By analyzing articulatory processes, researchers can reveal the physical basis of sound changes, making a substantial contribution to our knowledge of phonetic development.

One of the pioneering techniques in articulatory phonetics is Electromagnetic Articulography (EMA), which tracks the movement of small sensors attached to different articulators, such as the tongue, lips, and jaw, during speech. This method has been instrumental in providing detailed tem-

Methodology	Focus	Examples of Techniques	Strengths	Limitations
Acoustic Analysis	Examination of sound waves to discern changes in phonetic features	Spectrographic analysis, measurements of formant frequencies, pitch, intensity, and duration	Precise, quantifiable measurements of speech sounds	Challenges in interpretation, dependence on technological tools
Articulatory Phonetics	Physiological processes of sound production	Electromagnetic Articulography (EMA), Magnetic Resonance Imaging (MRI)	Detailed data on articulatory movements	Complexity and cost of equipment, potential influence on natural speech production
Perceptual Studies	How phonetic changes are received, processed, and interpreted by listeners	Categorical perception studies, misperception experiments	Insights into cognitive and perceptual aspects of sound change	Artificial nature of experimental settings, individual variability
Computational Modeling	Simulation of phonetic changes using mathematical and algorithmic approaches	Simulation models incorporating social interaction, cognitive and usage-based factors	Ability to incorporate diverse data, offering comprehensive simulations	Simplifications necessary for computational tractability, dependence on the quality of input data

Table 1: Summary of methodologies for detecting phonetic change, highlighting their focus, examples of techniques, strengths, and limitations.

poral and spatial data on articulatory movements, as demonstrated by Sanker (2018), who described how EMA can be used to study the articulatory settings associated with vowel changes. Another groundbreaking technology is Magnetic Resonance Imaging (MRI), which offers high-resolution images of the vocal tract during speech production. MRI studies, such as those conducted by Narayanan et al. (2004), have revealed the dynamic adjustments in vocal tract shape that underlie different phonetic sounds, shedding light on the articulatory configurations that may lead to phonetic change.

Despite the invaluable insights provided by articulatory phonetics, there are notable limitations to this approach. The complexity and cost of the required equipment, such as MRI machines and EMA systems, limit the accessibility of these techniques for many researchers (Pierrehumbert, 2001). Additionally, the invasive nature of some articulatory measurements, like those involving the placement of sensors on the speech organs, may influence natural speech production, potentially skewing the data collected (Ohala, 1971).

Moreover, articulatory data, while rich in detail, often require extensive interpretation to understand their implications for phonetic change. The relationship between specific articulatory movements

and the resultant acoustic signal can be complex, necessitating careful analysis to draw meaningful conclusions about the nature and direction of sound changes (Labov et al., 1971).

Despite these challenges, articulatory phonetics continues to be a vital component of phonetic change research. The method's capacity to directly monitor the physical creation of speech sounds provides a unique perspective on the processes behind sound change. With ongoing progress and the use of articulatory phonetic methods, future studies are sure to reveal more about the complexities and subtleties of the human speech production system, enriching our continuously advancing knowledge of linguistic phonetic change.

Perceptual Studies Perceptual Studies focus on understanding how phonetic changes are received, processed, and interpreted by listeners, shedding light on the cognitive and perceptual aspects of sound change. This approach involves experiments aimed at evaluating listeners' capacity to perceive, differentiate, and classify speech sounds, offering an understanding of the perceptual biases and factors that might influence phonetic change.

A foundational area of perceptual research concerns categorical perception, illustrating how speech sounds are perceived not continuously but rather as separate groupings (Lieberman, 1967). Studies in this domain, such as those by Fowler (1979), have shown how shifts in perceptual categories can lead to sound change, as listeners may begin to perceive borderline sounds as belonging to different categories over time.

Misperception experiments form another cornerstone of perceptual research, offering evidence on how phonetic changes can arise from systematic errors in speech perception. Ohala (2017) posited that many sound changes could be attributed to the listener-based misperception of speech sounds, a theory supported by experimental findings that demonstrated how listeners' misperceptions under adverse conditions could lead to changes in phonological systems (Babel and Johnson, 2010).

Perceptual studies also explore the influence of linguistic and non-linguistic contexts on sound perception. Research by Beddor et al. (2002) on coarticulatory effects illustrates how listeners' expectations about speech production can affect their perception of sounds, potentially leading to sound changes as these perceptual adjustments become phonologized.

Despite the invaluable insights provided by perceptual studies, this approach is not without limitations. One challenge is the artificial nature of experimental settings, which may not accurately reflect natural listening environments (Logan et al., 1989). Additionally, individual variability among listeners can introduce noise into perceptual data, complicating the interpretation of results (Bradlow et al., 1996).

However, perceptual studies continue to be a crucial aspect of research into phonetic change, providing access to the cognitive processes involved in language evolution. By integrating perceptual insights with findings from acoustic and articulatory research, we can gain a more comprehensive understanding of the factors driving phonetic change. Future research in this domain, especially studies utilizing naturalistic listening environments and longitudinal designs, aims to deepen our understanding of the complex interplay between perception, cognition, and linguistic change in influencing the sounds of languages.

Computational Modeling Computational Modeling provides an advanced framework for comprehending phonetic change, utilizing mathematical and algorithmic approaches to simulate the intricate dynamics of sound over time. This methodological approach enables the examination of hypotheses concerning the factors affecting phonetic change, offering a means to forecast future changes and retrospectively analyze the reasons for observed phonetic shifts.

One of the key contributions of computational modelling to the study of phonetic change is its ability to incorporate data from acoustic, articulatory, and perceptual studies into comprehensive models that can simulate the interaction of various factors influencing sound change. For example, Kirby and Sonderegger (2013) developed models that simulate the spread of sound changes within a linguistic community, incorporating insights into social interaction and network structure. Similarly, Wedel (2006) utilized computational models to examine the impact of competition between phonetic elements on sound change, emphasizing the significance of cognitive and usage-based factors.

Computational models also enable the study of the stability and alteration of phonological systems across generational time scales. Blevins (2004) employed computational methods to analyze the emergence of phonological patterns, demonstrating

how basic phonetic biases can result in the formation of complex sound systems. These models provide a powerful tool for testing theories of phonetic change in a controlled, simulated environment.

Despite their strengths, computational models face limitations, particularly regarding the simplifications necessary to make complex linguistic phenomena computationally tractable. Pierrehumbert (2001) observes that while models can simulate broad trends in phonetic change, they may miss the subtle interactions between individual speakers and the particular socio-linguistic contexts that influence real-world language use. Additionally, the accuracy of computational models heavily depends on the quality and comprehensiveness of the input data (Ohala, 1974), requiring careful consideration of the empirical data supporting these simulations.

In conclusion, computational modelling represents a crucial frontier in the study of phonetic change, offering unique perspectives into the dynamics of sound alteration. By synthesizing data from diverse methodological approaches, computational models provide a comprehensive view of the factors influencing phonetic change, emphasizing the interaction between cognitive, social, and physical influences on language. Future advancements in computational methods and increased collaboration with empirical data promise to further enhance our understanding of phonetic change, facilitating more accurate predictions and a better understanding of language processes.

4 Datasets

The study of phonetic change relies heavily on comprehensive datasets that cover both spatial and temporal dimensions. These datasets form the empirical basis for testing and developing theories related to phonetic change. Previous approaches have utilized a variety of datasets, ranging from historical linguistic corpora to contemporary speech recordings and experimental data collections. Each dataset type offers unique insights into the phonetic changes across different languages and periods.

Historical Corpora One crucial source of data for studying phonetic change is historical linguistic corpora. These corpora, such as the Middle English Dictionary database (Laing, 2013), offer written records that enable researchers to trace the development of phonetic features over centuries. Although these datasets offer invaluable longitudinal insights, they present challenges related to the interpretation of historical spelling conventions and the potential for anachronistic bias in phonetic reconstructions.

Contemporary Speech Contemporary speech recordings serve as another critical dataset, offering snapshots of linguistic variation and change in real-time. The Atlas of North American English (Labov et al., 2006) is a prime example, providing extensive acoustic measurements of vowel sounds across different American English dialects. These recordings allow for the quantitative analysis of phonetic variation and the identification of emerging phonetic shifts within specific linguistic communities.

Experimental Collections Experimental data collections, often generated through perceptual and articulatory studies, also contribute significantly to the datasets used in phonetic change research. For example, the UCLA Phonetics Lab Archive (Whalen and McDonough, 2019) contains a wide range of speech samples from multiple languages, gathered through controlled experimental settings. These datasets are particularly valuable for testing hypotheses about the mechanisms of phonetic change in a controlled environment, although they may not fully capture the complexity of naturalistic speech contexts.

Strengths and Limitations Each of these datasets has its strengths and limitations. Historical corpora and contemporary speech recordings offer real-world data on phonetic change but may lack the controlled conditions necessary for isolating specific variables of interest. In contrast, experimental data collections provide controlled conditions but may not reflect the full range of natural speech variability. Despite these challenges, the incorporation of varied datasets from historical, contemporary, and experimental sources remains essential for enhancing our comprehension of phonetic change, providing a diverse perspective on how languages change over time.

5 Outlook

The study of phonetic change over time is at a dynamic intersection of linguistics, cognitive science, and technology. The advancements in methodologies and the expansion of datasets have significantly broadened our understanding of how and why languages evolve phonetically. However, the path forward invites an interdisciplinary approach that not only integrates diverse methods and data

sources but also incorporates emerging technologies and theoretical insights. This section outlines the future directions and potential areas of focus in the study of phonetic change.

Interdisciplinary Methods The collaboration of cross-disciplinary methods is crucial for a comprehensive comprehension of phonetic change. Future research could profit from merging acoustic analysis with neurophysiological measures to scrutinize the neural aspects of speech perception and production alterations. Studies leveraging Electroencephalography (EEG) or functional Magnetic Resonance Imaging (fMRI) could provide insights into the cognitive processes involved in phonetic change, complementing the data obtained from traditional linguistic analysis (Blumstein et al., 2005).

Technological Advancements Advancements in machine learning and artificial intelligence offer promising tools for analyzing large linguistic datasets with unprecedented depth and precision. The application of deep learning algorithms to phonetic datasets could reveal subtle patterns of change that are not discernible through conventional analysis methods (Ismail et al., 2021). Additionally, machine learning models could be trained to predict future phonetic changes based on historical and contemporary linguistic data, offering a predictive framework for understanding language evolution.

Dataset Expansion The expansion and digitization of linguistic datasets are crucial for supporting these advanced analytical approaches. Efforts to digitize historical linguistic records and collect contemporary speech samples from a broader range of languages and dialects will enrich the datasets available for phonetic change research. Crowdsourcing and collaborative research platforms could play a significant role in gathering and curating these datasets, making them more accessible to researchers worldwide (Moore et al., 2020).

Inclusivity in Research Moreover, there is a growing need to study phonetic change in lesser-studied languages and dialects. Many languages around the world are underrepresented in linguistic research, limiting our understanding of phonetic change to a relatively narrow range of linguistic systems. Expanding the scope of research to include these languages could reveal novel patterns of phonetic evolution and contribute to a more comprehensive and inclusive understanding of language change.

In conclusion, the study of phonetic change over time stands to benefit greatly from an interdisciplinary, technologically informed, and inclusive research approach. By leveraging new technologies, expanding datasets, and embracing a broader range of linguistic systems, future research will continue to reveal the complex mechanisms driving the evolution of human language.

6 Conclusion

Learnings In conclusion, this survey paper has clarified the diverse aspects of phonetic change research, incorporating perspectives from historical analyses, contemporary observations, and advanced experimental methodologies. The amalgamation of these approaches has revealed the dynamic processes within phonetic change, providing a detailed understanding of how languages transform over time. Through the examination of acoustic analysis, articulatory phonetics, perceptual studies, and computational modelling, we have identified both the strengths and limitations of current research practices, emphasizing the potential for future technological and methodological advancements to deepen our comprehension of phonetic change.

Crucially, this review has emphasized the importance of diverse and robust datasets in phonetic change research. By drawing from historical linguistic corpora, contemporary speech recordings, and experimental data collections, researchers can overcome challenges related to sample representativeness and historical transcription accuracy, enhancing the reliability of their findings. Moreover, the paper advocates for an interdisciplinary approach to future research, suggesting that integrating methods from cognitive science, computational modelling, and neurophysiology could offer unprecedented insights into the mechanisms of language evolution.

Future Directions As we look to the future, it is clear that the path forward in phonetic change research will be marked by a greater emphasis on inclusivity, technological innovation, and cross-disciplinary collaboration. Expanding the scope of research to encompass lesser-studied languages and dialects will be critical for developing a more comprehensive understanding of phonetic change across linguistic systems. Additionally, leveraging advancements in machine learning, artificial intelli-

gence, and neuroimaging technologies will enable researchers to analyze linguistic data with greater depth and precision than ever before.

Inclusivity and Innovation Ultimately, this survey has contributed to a deeper appreciation of the complex interplay between phonetic change, cognitive processes, and sociolinguistic factors, reaffirming the value of experimental phonetics in studying the living history of language. As we persist in the complex realm of phonetic change research, it is the dedication to thoroughness, creativity, and analytical questioning that will advance the field of diachronic linguistics, elucidating the routes through which human language perpetually progresses.

References

Molly Babel and Keith Johnson. 2010. Accessing psycho-acoustic perception and language-specific perception with speech sounds. *Laboratory phonology*, 1(1):179–205.

Patrice Speeter Beddor, James D Harnsberger, and Stephanie Lindemann. 2002. Language-specific patterns of vowel-to-vowel coarticulation: Acoustic structures and their perceptual correlates. *Journal of Phonetics*, 30(4):591–627.

Juliette Blevins. 2004. *Evolutionary phonology: The emergence of sound patterns*. Cambridge University Press.

Sheila E Blumstein, Emily B Myers, and Jesse Rissman. 2005. The perception of voice onset time: an fmri investigation of phonetic category structure. *Journal of cognitive neuroscience*, 17(9):1353–1366.

Ann R Bradlow, Gina M Torretta, and David B Pisoni. 1996. Intelligibility of normal speech i: Global and fine-grained acoustic-phonetic talker characteristics. *Speech communication*, 20(3-4):255–272.

Carol A Fowler. 1979. "perceptual centers" in speech production and perception. *Perception & Psychophysics*, 25(5):375–388.

Carol A Fowler. 1996. Listeners do hear sounds, not tongues. *The Journal of the Acoustical Society of America*, 99(3):1730–1741.

Robert Allen Fox and Ewa Jacewicz. 2009. Cross-dialectal variation in formant dynamics of american english vowels. *The Journal of the Acoustical Society of America*, 126(5):2603–2618.

Larry M Hyman. 2001. Fieldwork as a state of mind. *Linguistic fieldwork*, pages 15–33.

Larry M Hyman and Frans Plank. 2018. *Phonological typology*. De Gruyter Mouton Berlin/Boston.

Muhammad Ismail, Shahzad Memon, Lachhman Das Dhomeja, Shahid Munir Shah, Dostdar Hussain, Sabit Rahim, and Imran Ali. 2021. Development of a regional voice dataset and speaker classification based on machine learning. *Journal of Big Data*, 8:1–18.

James Kirby and Morgan Sonderegger. 2013. A model of population dynamics applied to phonetic change. In *Proceedings of the Annual Meeting of the Cognitive Science Society*, volume 35.

William Labov. 1963. The social motivation of a sound change. *Word*, 19(3):273–309.

William Labov. 1965. On the mechanism of linguistic change. *Georgetown monographs on language and linguistics*, 18:91–114.

William Labov, Sharon Ash, and Charles Boberg. 2006. *The atlas of North American English: Phonetics, phonology and sound change*. Mouton de Gruyter.

William Labov et al. 1971. The study of language in its social context. *Advances in the Sociology of Language*, 1(152-216).

Margaret Laing. 2013. A linguistic atlas of early middle english 1150–1325 (laeme, version 3.2).

Roger Lass. 1990. What, if anything, was the great vowel shift? In *History of Englishes: Proceedings of the 6th ICEHL conference, Helsinki*, pages 144–155.

Philip Lieberman. 1967. Intonation, perception, and language. *MIT Research Monograph*.

John S Logan, Beth G Greene, and David B Pisoni. 1989. Segmental intelligibility of synthetic speech produced by rule. *The Journal of the Acoustical Society of America*, 86(2):566–581.

Meredith Moore, Piyush Papreja, Michael Saxon, Visar Berisha, and Sethuraman Panchanathan. 2020. Uncommonvoice: A crowdsourced dataset of dysphonic speech. In *Interspeech*, pages 2532–2536.

Shrikanth Narayanan, Krishna Nayak, Sungbok Lee, Abhinav Sethy, and Dani Byrd. 2004. An approach to real-time magnetic resonance imaging for speech production. *The Journal of the Acoustical Society of America*, 115(4):1771–1776.

John J Ohala. 1971. The role of physiological and acoustic models in explaining the direction of sound change. *Project on Linguistic Analysis Reports*, 15(15):25–40.

John J Ohala. 1974. A mathematical model of speech aerodynamics. *Annual Report of the Institute of Phonetics University of Copenhagen*, 8:11–22.

John J Ohala. 2017. Phonetics and historical phonology. *The handbook of historical linguistics*, pages 667–686.

John J Ohala and Charles Jones. 1993. The phonetics of sound change. *Historical linguistics: Problems and perspectives*, 237:278.

Janet Pierrehumbert. 2001. Stochastic phonology. *Glot international*, 5(6):195–207.

Janet B Pierrehumbert. 2003. Probabilistic phonology: Discrimination and robustness.

Chelsea Sanker. 2018. A survey of experimental evidence for diachronic change. *Linguistics Vanguard*, 4(1):20170039.

Mónica A Wagner, Mirjam Broersma, James M McQueen, Sara Dhaene, and Kristin Lemhöfer. 2021. Phonetic convergence to non-native speech: Acoustic and perceptual evidence. *Journal of Phonetics*, 88:101076.

Andrew B Wedel. 2006. Exemplar models, evolution and language change.

Douglas H Whalen and Joyce McDonough. 2019. Under-researched languages: Phonetic results from language archives. In *The Routledge handbook of phonetics*, pages 51–71. Routledge.