

# **1. Anatomy and physiology of speech production**

- 1.1 Components of the speech production system (p1)
  - 1.1.1 the subglottal system (p1)
  - 1.1.2 the larynx (p5)
    - 1.1.2.1 supporting structures for the vocal folds (p5)
    - 1.1.2.2 properties of the vocal folds (p9)
    - 1.1.2.3 laryngeal structures above the vocal folds (p13)
    - 1.1.2.4 extrinsic laryngeal muscles (p13)
  - 1.1.3 the vocal tract above the larynx (p15)
    - 1.1.3.1 pharynx (p15)
    - 1.1.3.2 soft palate and nasal cavity (p17)
    - 1.1.3.3 oral cavity, tongue and mandible (p20)
    - 1.1.3.4 vocal tract volume (p24)
    - 1.1.3.5 lips (p24)
    - 1.1.3.6 vocal tract length (p25)
    - 1.1.3.7 mechanical properties of vocal tract wall (p26)
- 1.2 Basic aerodynamic process (p27)
  - 1.2.1 static airflow in tubes and orifices (p27)
    - 1.2.1.1 airflow in a uniform tube (p27)
    - 1.2.1.2 airflow through a constriction in a tube (p29)
  - 1.2.2 airflow and pressure in the vocal tract for typical static configurations (p32)
    - 1.2.2.1 configurations with a supraglottal constriction (p32)
    - 1.2.2.2 constriction at the glottis (p34)
    - 1.2.2.3 combined effect of glottal and supraglottal constrictions (p35)
- 1.3 kinematics of articulatory movements (p38)
  - 1.3.1 the respiratory system below the larynx (p40)
  - 1.3.2 adjustment of vocal fold tension (p41)
  - 1.3.3 movement of glottal and supraglottal structures (p41)
    - 1.3.3.1 adjustments of glottal opening (p42)
    - 1.3.3.2 tongue body and tongue root (p42)
    - 1.3.3.3 soft palate (p43)
    - 1.3.3.4 lip rounding (p44)
    - 1.3.3.5 timing of movements toward and away from consonantal constrictions (p44)
    - 1.3.3.6 overall speech rates (p48)
- 1.4 time-varying airflows and pressures (p49)
  - 1.4.1 model of the respiratory system (p49)
  - 1.4.2 model of the supraglottal system (p51)

## **2 Source Mechanisms (p55)**

- 2.1 Periodic glottal source (p55)
  - 2.1.1 The basic process of vocal fold vibration (p56)
  - 2.1.2 Waveform of glottal airflow (p65)
  - 2.1.3 Manipulation of frequency of vibration (p72)
  - 2.1.4 Effects of changes in alveolar pressure (p75)
  - 2.1.5 Conditions for glottal vibrations (p80)
  - 2.1.6 Factors affecting the glottal waveform (p82)
    - 2.1.6.1 Pressed voicing (p82)
    - 2.1.6.2 Breathy voicing (p85)
  - 2.1.7 Effect of a vocal tract constriction on glottal vibration (p92)
    - 2.1.7.1 Moderate constriction sizes (p93)
    - 2.1.7.2 Narrow constrictions or closure (p94)
  - 2.1.8 Models of the glottal source (p97)
- 2.2 Turbulence noise sources (p100)
  - 2.2.1 Mechanisms of turbulence noise generation at a constriction in a tube (p100)
  - 2.2.2 Sound pressure source due to turbulence in the flow (p101)
  - 2.2.3 Monopole source due to turbulent flow (p106)
  - 2.2.4 Noise generation for a configuration with two constriction (p108)
  - 2.2.5 Turbulence noise at the release of a stop consonant (p112)
  - 2.2.6 Simultaneous glottal vibration and turbulence noise (p115)
- 2.3 Transient sources (p117)
- 2.4 Sources produced by suction (p121)
- 2.5 Vibration of supraglottal structures (p124)

## **3 Basic acoustics of vocal tract resonators (p127)**

- 3.1 Speech production in terms of source, transfer function, and radiation characteristic (p127)
- 3.2 General form of the vocal tract transfer function (p130)
- 3.3 Natural frequencies and transfer functions for various resonator shapes (p136)
  - 3.3.1 Uniform tubes (p138)
  - 3.3.2 Lumped acoustic mass and compliance (p140)
  - 3.3.3 Helmholtz resonator (p141)
  - 3.3.4 Natural frequencies for coupled resonators (p142)
  - 3.3.5 Effects on the formant frequencies of perturbations in the area functions (p148)
- 3.4 Losses and effects of walls of resonators (p152)
  - 3.4.1 Radiation impedance (p153)
  - 3.4.2 Impedance of vocal tract walls (p156)
  - 3.4.3 heat conduction and viscosity (p160)

- 3.4.4 Summary of effects of radiation and wall losses (p161)
- 3.4.5 Effect of airflow at a constriction (p163)
- 3.4.6 Impedance of glottal opening (p165)
- 3.5 Excitation of acoustic resonators (p167)
  - 3.5.1 Some general principles
  - 3.5.2 Excitation from glottal vibration (p168)
  - 3.5.3 Excitation by turbulence noise in the vicinity of the glottis (p171)
  - 3.5.4 Sources above the glottis (p175)
    - 3.5.4.1 Turbulence noise source at an obstacle or surface
    - 3.5.4.2 Effects of back cavity (p179)
    - 3.5.4.3 Distributed sources (p183)
    - 3.5.4.4 Monopole turbulence noise source
    - 3.5.4.5 Transient source (p184)
- 3.6 Nasal coupling and other side branches (p187)
  - 3.6.1 Acoustic properties of the nasal tract (p189)
  - 3.6.2 Transfer function with nasal coupling (p190)
  - 3.6.3 Side branch or bifurcation within the vocal tract: lateral and retroflex consonants (p194)
  - 3.6.4 Effects of coupling to the subglottal cavities (p196)
- 3.7 Radiation of sound from the vocal tract (p197)
  - 3.7.1 Radiation from the mouth opening
  - 3.7.2 Radiation from the walls of the vocal tract (p198)

## **4 Auditory processing of speechlike sounds (p203)**

- 4.1 Auditory physiology (p203)
  - 4.1.1 External and middle ear (p203)
  - 4.1.2 Cochlear mechanics (p205)
  - 4.1.3 Basic auditory nerve responses (p212)
  - 4.1.4 Auditory nerve responses to speech like stimuli (p218)
- 4.2 Basic auditory psychophysics (p224)
  - 4.2.1 Absolute thresholds for tones (p224)
  - 4.2.2 Loudness; sensitivity to changes in amplitude or spectrum (p225)
  - 4.2.3 Pitch perception; discrimination of frequency of tones and other spectral prominences (p227)
  - 4.2.4 Discrimination of duration and temporal order (p228)
  - 4.2.5 Masking: simultaneous and nonsimultaneous (p229)
  - 4.2.6 Masking and frequency selectivity (p233)
  - 4.2.7 Perception of sounds with two or more spectral prominences (p238)

## **5 Phonological representation of utterances (p243)**

- 5.1 Words, segments, features (p243)
- 5.2 Articulator-free features and landmarks (p245)
- 5.3 Articulator-bound features (p249)

## **6 Vowels: acoustic events with a relatively open vocal tract (p257)**

- 6.1 Formant bandwidths for vowels (p258)
- 6.2 The high vowels (p260)
  - 6.2.1 First-formant frequency and bandwidth for high vowels (p261)
  - 6.2.2 Perception and auditory response for high vowels (p264)
  - 6.2.3 Summary: high vowels (p267)
- 6.3 The non-high vowels : high first – formant frequency (p268)
  - 6.3.1 Articulatory and acoustic characteristics of low vowels (p268)
  - 6.3.2 Vowels intermediate between high and low vowels (p271)
  - 6.3.3 Auditory response for non-high vowels (p273)
- 6.4 Front-back tongue body position (p273)
  - 6.4.1 Low vowels (p274)
  - 6.4.2 High vowels (p277)
  - 6.4.3 Vowels with intermediate height (p282)
  - 6.4.4 Summary of front-back distinction (p283)
- 6.5 Some further attributes of vowels in a system based on high-low and front-back distinctions (p284)
  - 6.5.1 Derivation from perturbation theory (p284)
  - 6.5.2 Some data from American English (p287)
  - 6.5.3 Spectrum shapes and equivalent F2' (p288)
- 6.6 The rounding feature: enhancing the prominence of a spectral peak (p290)
- 6.7 The constricted-nonconstricted or tense-lax distinction (p294)
- 6.8 Effects of laryngeal configuration and acoustic coupling to the subglottal system (p299)
- 6.9 Nasalization of vowels (p303)
  - 6.9.1 Theoretical analysis of vowel nasalization (p303)
  - 6.9.2 Examples of acoustic data for nasal vowels (p306)

## **7 The basic stop consonants : bursts and formant transitions (323)**

- 7.1 Overview of basic stop consonants (p324)
- 7.2 Aerodynamic and articulatory description (p324)
- 7.3 Low-frequency sound output (p331)
- 7.4 High-frequency sound output (p340)
  - 7.4.1 General description (p340)
  - 7.4.2 Labial stop consonants (p340)
    - 7.4.2.1 Formant transitions (p340)

- 7.4.2.2 Changes in source amplitude and spectral characteristics (p344)
- 7.4.3 Alveolar stop consonants (p355)
  - 7.4.3.1 Formant transitions (p355)
  - 7.4.3.2 Changes in source amplitude and spectral characteristics (p357)
- 7.4.4 Velar stop consonants (p365)
  - 7.4.4.1 Formant transitions (p365)
  - 7.4.4.2 Changes in source amplitude and spectral characteristics (p368)
- 7.5 Summary of acoustic characteristics of voiceless unaspirated stop consonants (p375)

## **8 Obstruent consonants (p379)**

- 8.1 Fricative consonants (p379)
  - 8.1.1 Aerodynamic and articulatory description (p380)
  - 8.1.2 Low-frequency characteristics (p384)
  - 8.1.3 Turbulence noise source (p387)
  - 8.1.4 Labial fricatives (p389)
  - 8.1.5 Alveolar fricatives (p398)
  - 8.1.6 Palatoalveolar fricatives (p403)
  - 8.1.7 Summary of characteristics of voiceless fricative consonants (p411)
- 8.2 Affricates (p412)
  - 8.2.1 Articulatory movements and aerodynamic parameters (p413)
  - 8.2.2 Acoustic characteristics (p416)
  - 8.2.3 Summary of characteristics of Palatoalveolar affricates (p422)
- 8.3 Consonants with aspiration (p422)
  - 8.3.1 The consonant /h/: the transition between modal voicing and voiceless aspiration (p423)
    - 8.3.1.1 Low-frequency characteristics of /h/ (p424)
    - 8.3.1.2 Characteristics of turbulence noise at the glottis (p428)
    - 8.3.1.3 Tracheal coupling during /h/ (p436)
    - 8.3.1.4 Consequences of a constriction in the supraglottal airway (p441)
    - 8.3.1.5 Turbulence noise at the glottis during breathy and modal voicing (p445)
  - 8.3.2 Voiceless aspirated stop consonants (p451)
    - 8.3.2.1 Laryngeal movements, airflow and voicing onset (p451)
    - 8.3.2.2 Frication and aspiration noise (p457)
    - 8.3.2.3 Summary of characteristics of voiceless aspirated (p464)
- 8.4 Voicing for obstruents (p465)
  - 8.4.1 Voiced unaspirated stop consonants (p468)
  - 8.4.2 Voiced aspirated stop consonants (p474)
  - 8.4.3 Voiced fricative consonants (p477)
  - 8.4.4 Summary of characteristics of voiced obstruent consonants (p483)

## **9 Sonorant consonants (p487)**

- 9.1 Nasal consonants (p487)
  - 9.1.1 Articulatory description (p487)
  - 9.1.2 Low-frequency sound output (p489)
  - 9.1.3 High-frequency sound output (p494)
    - 9.1.3.1 labial nasal consonants (p494)
    - 9.1.3.2 Alveolar nasal consonants (p499)
    - 9.1.3.3 Velar nasal consonants (p507)
  - 9.1.4 Summary of acoustic characteristics of nasal consonants (p512)

- 9.2 Glides (p513)
  - 9.2.1 Low-frequency characteristics of glides (p513)
  - 9.2.2 High-frequency characteristics of glides (p523)
    - 9.2.2.1 Labial glide (p523)
    - 9.2.2.2 Palatal glide (p526)
  - 9.2.3 Summary of characteristics of glides (p530)

- 9.3 liquids (p532)
  - 9.3.1 Low-frequency characteristics of liquids (p533)
  - 9.3.2 High-frequency characteristics of liquids (p535)
    - 9.3.2.1 Retroflex liquid consonant (p535)
    - 9.3.2.2 Laterals (p543)
  - 9.3.3 Summary of characteristics of liquids (p554)

## **10 Some influences of context on speech sound production (p557)**

- 10.1 Consonant sequences at syllable onset (p557)
- 10.2 Consonant sequences across syllable boundaries (p565)
- 10.3 Some effects of context on vowel production (p572)
- 10.4 Reduced vowels (p574)
- 10.5 Summary and discussion (p579)