Foundations in Music Psychology

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Foundations in Music Psychology

Theory and Research

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Annabel J. Cohen

Introduction

The human voice provides every individual with a remarkable instrument for making music. Yet, in scholarly discourse on music, this universally available instrument often plays second fiddle to musical instruments that are human-made. Over the last decade, however, attention to research on human singing is increasing, with respect to not only underlying mechanisms but also psychological significance.[1]

Singing is many things, and it is not easy to define. It is a form of vocal communication, a complex motor behavior, and a means of artistic expression. According to the authoritative *Grove Music Online*, “Singing is a fundamental mode of musical expression. … arguably [the voice is] the most subtle and flexible of musical instruments, and therein lies much of the fascination of the art of singing” (Jander, Harris, Fallows, & Potter, 2017). Historically, influential thinkers of the nineteenth century such as Charles Darwin, Herbert Spencer, and John Hughlings Jackson tied singing more to emotion than speech, and, in those early times, the dissociation between singing and speaking in aphasia was also recognized (Johnson & Graziano, 2015). Yet, singing is not necessarily more emotional than speech, nor is the boundary between singing and speaking well defined. The notion of a speech-song continuum proposed by ethnomusicologist George List (1963) has led to ongoing debate. While singing serves a fundamental role in music, its impact goes far beyond this. As described in the *World in Six Songs* (Levitin, 2008), songs and singing nurture friendship, bring joy and comfort, anchor religion, transmit knowledge, and communicate and foster love. Due to the social, cultural, and biological influences on singing, the study of singing draws on many disciplines and admits to many forms of methodological exploration and analysis.

This chapter reviews research on singing from a music-psychological perspective. The scope is broad because singing connects with many if not most issues in music psychology, as well as raising additional unique issues particular to the human voice. Other chapters of the book (e.g., on brain mechanisms, timbre, development, and musical disorders) provide foundations for the five sections of the chapter. The first describes the anatomy and mechanics of the vocal apparatus. The second discusses brain mechanisms that control the auditory-motor feedback system underlying singing. The third reviews the developmental course of singing, various singing skills, and influences of gender and culture. The fourth reviews the role of singing in promoting positives behaviors, such as acquiring literacy, fostering cultural understanding and empathy, and improving wellbeing in conditions of compromised physical and mental health. The final section looks to the way forward in addressing pressing questions such as the relative merit of engaging in singing versus engaging in performance of a musical instrument. The chapter concludes with reference to the value of a future dynamic systems model of singing that accommodates experiential influences and universal factors in order to account for both the shared and the idiosyncratic aspects of singing behaviors.

Biomechanics of the Singing Voice

At first glance, singing may appear to engage only a small portion of the human body, particularly the mouth and neck areas. In reality singing involves much more. Figure 17.1 illustrates schematically the basic three-part anatomy of the vocal production system. The system consists of (a) a power supply from the lungs to produce air pressure and air flow that impacts (b) the vocal folds whose vibrations create the sound source—the complex wave (glottal source spectrum) that passes through (c) the vocal tract, which consists of the upper larynx (windpipe) and the vocal cavities of the mouth. The changing shape and natural resonances of the vocal tract (sound transfer curve formants) filter the original source spectrum of the sound, so as to become the produced sound (radiated spectrum) that has particular aesthetic and phonetic qualities. In this complex system, individual organs serve multiple functions, vocal and nonvocal. While there is a good understanding of the voice production process, much remains unknown in regard to voice physiology and biomechanics (see for review: Kob et al., 2011; Zhang, 2016). The following describes the basic principles and gives a sense of the neurological challenge of controlling the multitude of muscle systems responsible for the pitch, loudness, and quality of the singing voice.

Source-Filter Model of Singing

Figure 17.1 originates with Johan Sundberg (1987), pioneering author of *The Science of the Singing Voice*.[2] The figure is based on an acoustic theory of speech production, known as the *source-filter model* (Fant, 1960), in which *source* refers to the vocal folds acting as an oscillator (b, figure 17.1), and *filter* refers to the vocal tract (c, figure 17.1). Sundberg's adaptation of the

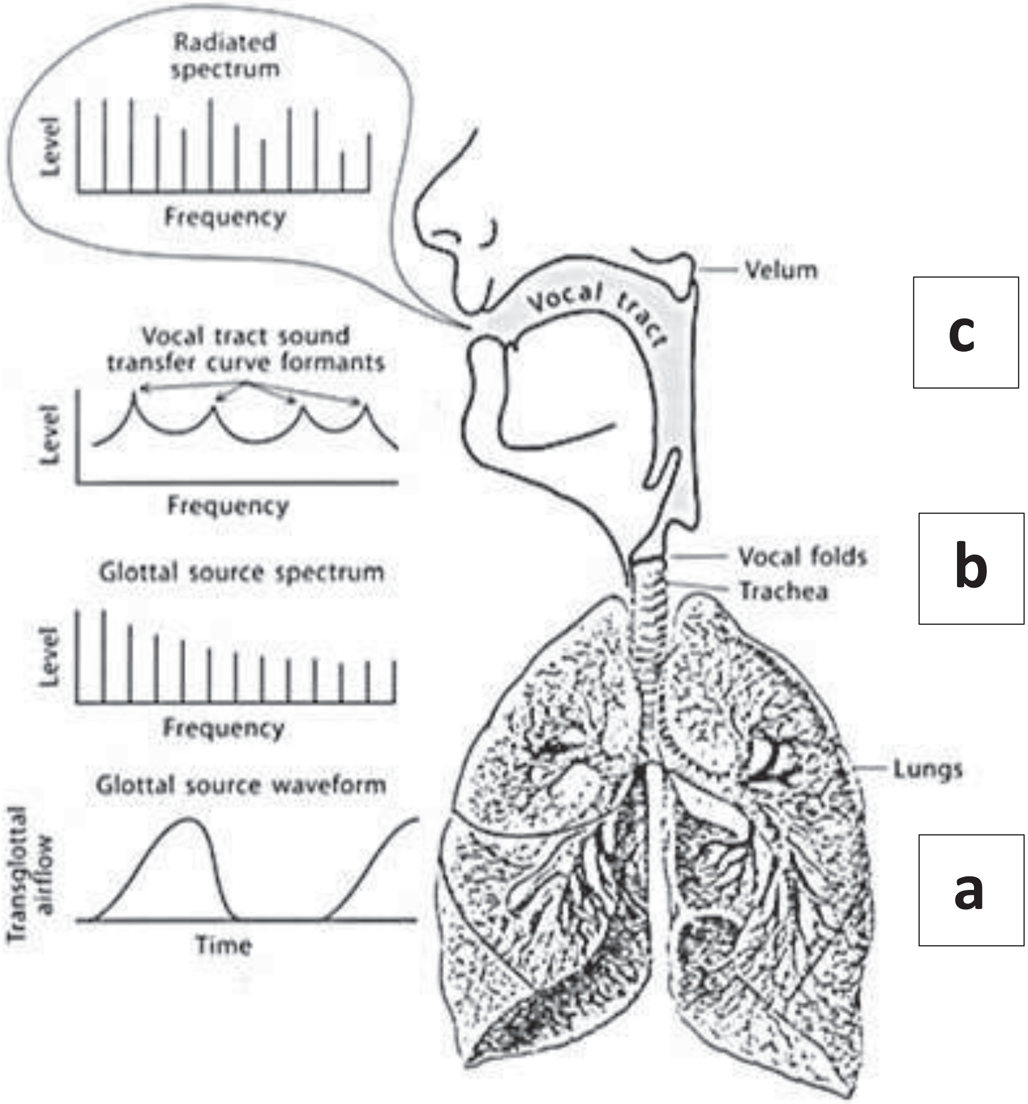

Figure 17.1
The basic anatomy and physiology of singing and its acoustic effects from (a) the respiratory system, (b) the vocal folds, and (c) the vocal tract.
Source: Image from Sundberg (1996, p. 1096. Used with permission.

source-filter model accounted for how the sounds of singing are generated at the vocal folds (b) and filtered by the changing vocal tract structure (c).

(a) Respiratory system produces sub-glottal pressure The airspace between the vocal folds is referred to as the *glottis*, which gives rise to the term *subglottal pressure* produced below by the lungs at (a). Contraction of the abdominal muscles builds the pressure below the closed glottis, creating a pressure drop across the larynx, which eventually exceeds the threshold sufficiently to set the vocal folds into vibration. The extent of pressure required depends on both the degree of muscle contraction as well as resistance at the vocal folds. Subglottal pressure plays a role in determining the intensity of the voice and, to a lesser extent, the pitch.

(b) The vocal folds (or vocal cords) Figure 17.2a provides an image of human vocal folds in open position (*abduction*), revealing the glottis. Figure 17.2b (*adduction*) shows the folds closed and hiding the glottis. In infancy, the vocal folds at rest are approximately 3 mm (.12 inches) in length and grow in adult females to 9–13 mm and in adult males to 15–20 mm (Sundberg, 1987). Vocal fold vibration in the audible range leads to audible pitch. The process is often referred to as *phonation*. The pitch (fundamental frequency, referred to as f_o) in cycles (oscillations) per second (Hz) produced by the vibrating vocal folds increases with

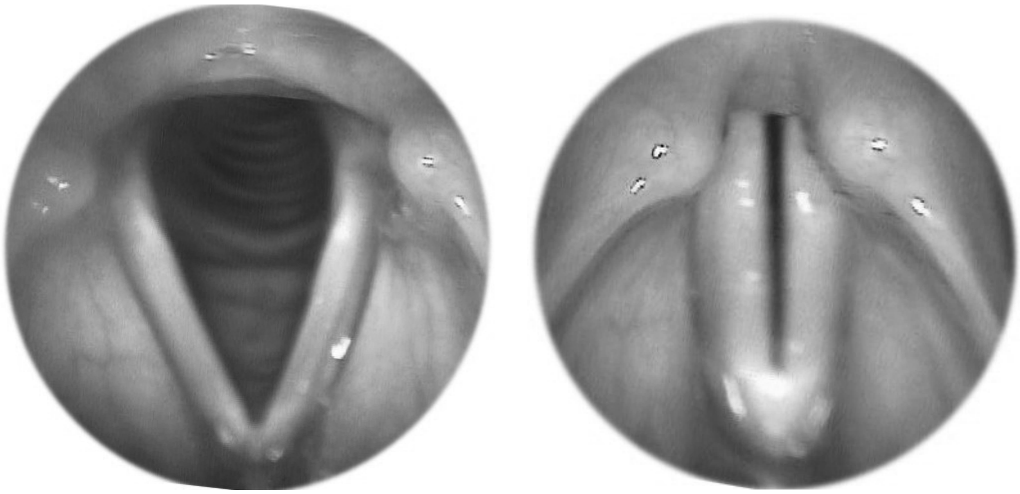

Figure 17.2
Vocal folds as seen through an endoscope: (a) in open position showing glottis (abduction) and (b) in closed position hiding glottis (adduction).
Source: Used with permission of the Lions Voice Clinic of the University of Minnesota and Professor Deirdre D. Michael.

their increasing tension and stiffness and their decreasing mass and length. Pairs of muscles control positions of laryngeal cartilages, changing these parameters of the vocal folds so as to raise or lower the f_o intended for the particular musical context. Given this physical and physiological system, the approximate frequency range of the singing voice (vocal fold range) lies between the typically lowest bass note for males ($f_o = E_2$ or 82.4 Hz[3]) to the typically highest soprano note ($f_o = C_6$ or 1046.5 Hz) (Sundberg, 2000), although sopranos with classical training can often sing higher, and those who have mastered the art of overtone singing, can sing higher still. Figure 17.3 shows the range of the voice in the context of the ranges of other musical instruments. The ranges differ depending on the laryngeal mechanism employed, for example, chest voice versus falsetto (Kob et al., 2011). In psychological studies, the f_o of the singing voice is typically measured from acoustical recordings using pitch analysis software such as Praat (Boersma & Weenink, 2017).[4] Vocal fold vibration, however, can also be measured directly with noninvasive techniques.[5]

(c) Vocal tract The discussion so far has considered only the fundamental frequency (f_o) of the tones produced at the vocal cords. Each of these tones, however, is a complex sound containing harmonics at whole integer multiples of f_o—glottal source spectrum in the left panel of figure 17.1 at level (b) represents the spectrum of harmonics at integer multiples of a fundamental frequency (f_o). Thus, as also described in chapter 3 of this book, on timbre, for a tone of (middle) C_4 at 261.6 Hz, the 2nd harmonic ($2f_o$) appears as the octave at 523.2 Hz, the 3rd ($3f_o$) at 784.8 Hz, the 4th ($4f_o$) at 1046.4 Hz, and so on. These harmonics contribute to the quality of the voice—what distinguishes the singing and speaking voice of one person from another—and also to the distinctiveness of speech sounds (*phonemes*), particularly vowels.

These differences in voice quality and phonetic characteristics arise from the filtering by the vocal tract resonances. The jaw, tongue mass, and tongue control the properties of the upper vocal tract, while other muscle systems control properties of the larynx. The entire vocal track, which is like a hollow tube closed at one end, has natural resonances at several frequency bands, called *formants*. These frequency bands characterize vowels. The formant frequencies alter when the articulators (e.g., jaw, tongue) change the shape of the vocal track and its resonant properties. The f_o produced by the vibrating vocal folds is unrelated to the frequencies of the formants (Ladefoged, 2000). However, the experienced singer is able to learn to control the vocal tract shape so as to adjust a resonance to match a harmonic of f_o, and consequently enhance the loudness of the overall sound produced (Henrich, Smith, & Wolfe, 2011).

Professional male singers acquire the ability to shape their vocal tracts so as to cluster several formants into the frequency range of approximately 2.5–3.5 kHz, a range of high human

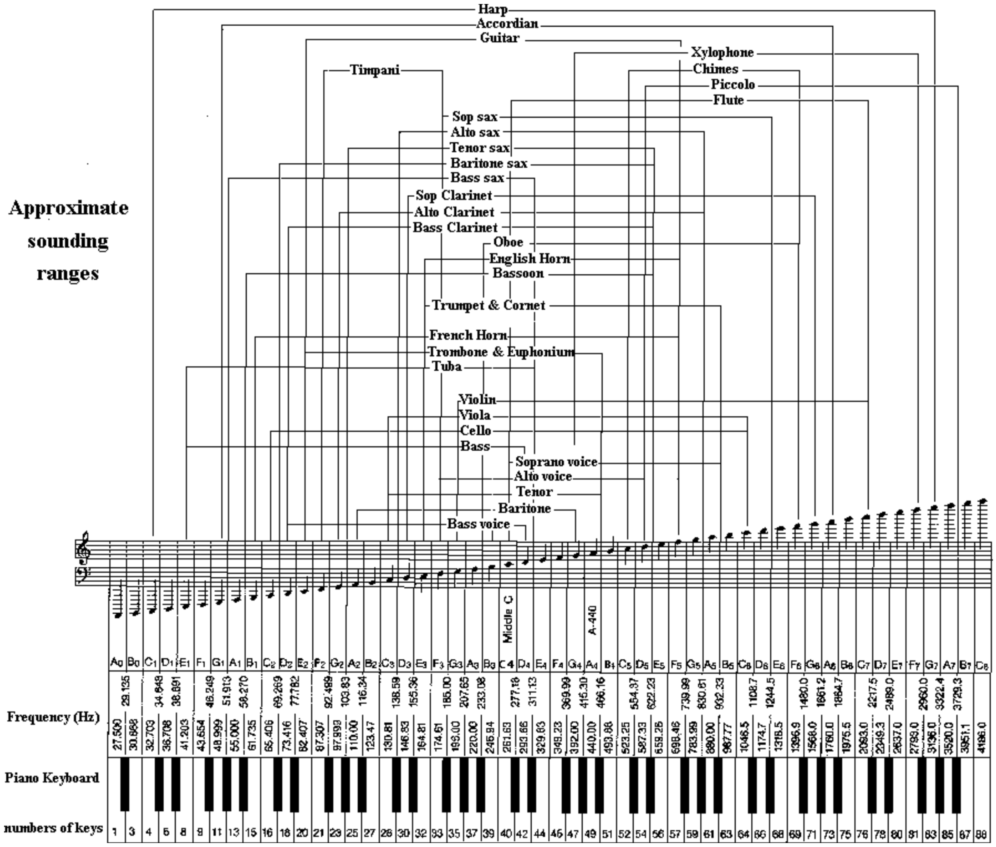

Figure 17.3

Approximate ranges of the human vocal registers (bass, baritone, tenor, alto, soprano) in the context of the 8 octaves of the piano keyboard and ranges of orchestral instruments.

Source: http://solomonsmusic.net/insrange.htm

hearing sensitivity (Plack, 2014). This phenomenon, discovered by Bartholemew (1934), has been most extensively researched by Sundberg (2000, 2003), and is known as the singer's formant.[6] Male Western opera singers have a high intensity of frequencies in this especially audible range, enabling, without amplification, audibility over an orchestral accompaniment. The singer's formant is absent in professional male vocalists who are trained to sing Chinese opera (Sundberg, Gu, Huang, & Huang, 2012). Hunter, Svec, and Titze (2006) questioned whether Western operatic training to emphasize harmonics in the 3,000 Hz range arose because it was physiologically the easiest way to increase output or because it was the range that matched the optimal sensitivity of human hearing.

Voice Range Profile (VRP)

The *voice range profile* (VRP), also called the *phonetogram*, provides a picture of the singer's frequency range and intensity levels. It is obtained by measuring the maximum range of pitches and dynamics that a singer can produce on one single vowel (Ternström, Pabon, & Södersten, 2016). The physical characteristics of any acoustic musical instrument limit the range and quality of sounds that can be produced. As with any other musical instrument, maximally exploiting the vocal instrument depends on the skill and intuition of the musician.[7] Figure 17.4 presents the average voice range profiles for groups of sopranos, mezzo-sopranos, and contraltos, and show considerable overlap in the intensity dimension and considerable differentiation between sopranos and contraltos with respect to pitch (frequency).

The physical properties of the vocal instrument may change either through effects of age or health, or through use and deliberate practice. According to Pabon Stallinga, Södersten, and Ternström (2014), "Training the voice reshapes the vocal instrument to some degree and improves the control of the instrument to a larger degree" (p. 36). One of the main goals of vocal training is to produce as beautiful a sound as possible over a functional range (not necessarily the widest range) (Lamarche, 2009). In work with experienced opera singers, Lamarche, Ternström, and Pabon (2010) noted the importance of task instructions on the outcome of the profile (e.g., instructions to simply produce a sound versus to produce a sound in one's best singing voice).

Successfully singing one note of a desired pitch, intensity, and quality is a highly sophisticated human ability, an ability that is yet further surpassed by singing meaningful and aesthetically pleasing sequences of such notes. As we have seen in this section, singing entails the coordination of many parts of the body. It is therefore no surprise that singing engages the coordination of many parts of the brain, as described in the next section.

Brain Mechanisms Underlying Singing

A Feedback System

Meaningful vocalization entails neural activation of muscles that control respiration, vocal fold vibration, and vocal tract configuration. The system of neural activity that drives vocal production also relies on auditory and sensorimotor motor feedback (e.g., Dalla Bella, Berkowska, & Sowinski, 2011; Pfordresher et al., 2015; Tsang, Friendly, & Trainor, 2011). The process is complex, and both the precision for frequency and timing and the sound quality required by singing can exceed the requirements for speaking.[8] Figure 17.5 represents as a cartoon the task of singing a song and highlights the coordination of two complex processes: (A) listening to a song and forming a representation or mental model of it for guiding (B) the vocal

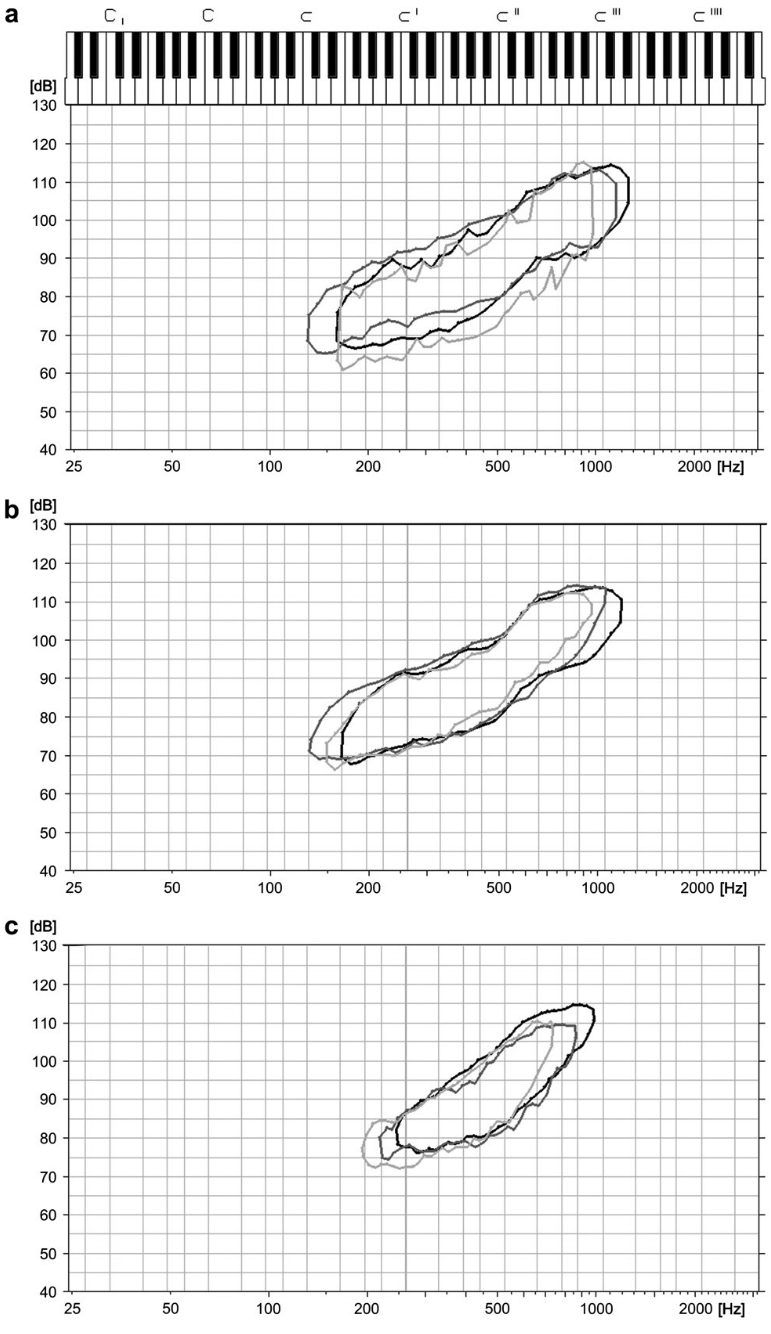

Figure 17.4

Average Voice Range Profile (VRP) contours for 16 sopranos in black, 8 mezzo-sopranos (dark gray), and 6 contraltos in light gray on a task of singing the various pitches as quietly and as loudly as possible. Source: Lamarche, Ternström, & Pabon (2010, p. 420). Used with the permission of Elsevier.

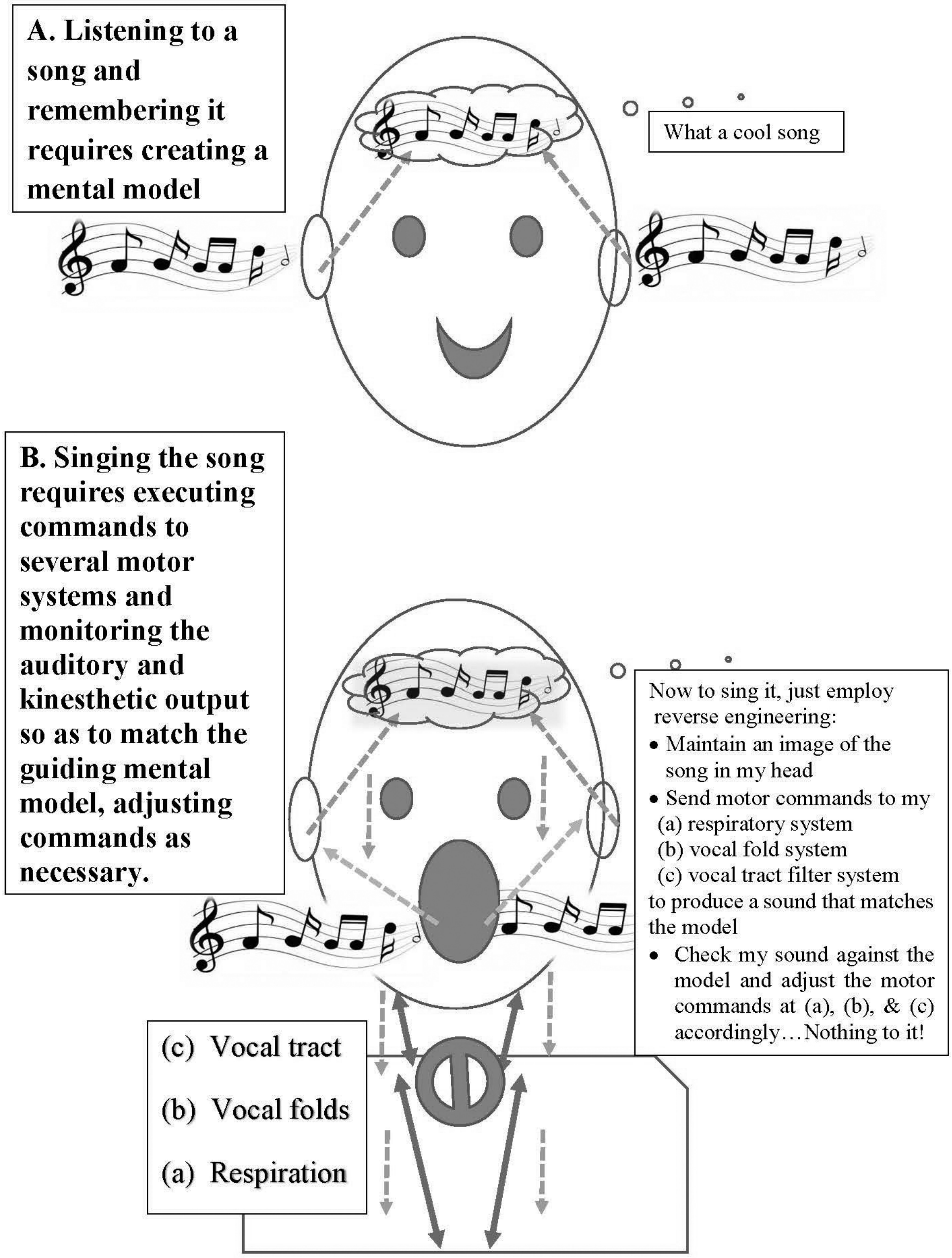

Figure 17.5

Representation of the complex tasks carried out in singing a familiar song: (A) creation of a mental model (notation cloud) of the song—implied are syntactic, semantic, and aesthetic aspects; (B) mental model of the melody guides execution of motor commands for respiration, vocal fold oscillation, and vocal tract resonance required for sound production and monitoring acoustical and kinaesthetic output, respectively, so as to sing the closest match to the sequential information represented in the mental model.

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melody production system by determining what motor activities are required to reproduce the melodic target, as defined through audio-motor-somatosensory feedback. The complexity of the processes might explain why some people feel they cannot sing (although the spirit of this chapter is that almost everyone is born with the ability to sing, which can be facilitated by practice and confidence).

Auditory feedback Hearing one's own voice and matching it to a model is critical to singing, and hence the neural structures that support melody perception play a role in singing. The entire auditory system is involved in hearing oneself sing. A detailed discussion of brain mechanisms underlying music perception is found in chapter 1 by Andrew Oxenham and chapter 10 by Stefan Koelsch. The perception of the quality of the voice entails timbre perception, as addressed in chapter 3 by Stephen McAdams. Menon et al. (2002) and Belin, Zatorre, Lafaille, Ahad, and Pike (2000) showed that regions of the superior temporal sulcus responded to the human voice rather than to environmental sounds.

Somatosensory feedback A crucial distinction between encoding a melody sung by someone else and encoding a melody sung by oneself arises from *somatosensory feedback* from the respiratory, vocal folds, laryngeal, and orofacial systems. *Somatosensory feedback* refers to the sense of movement (kinesthesia) and the sense of body position (proprioception). The neural signals from somatosensory feedback travel to a dedicated region of the brain called somatosensory cortex (S1) and the insula. According to Riecker, Ackermann, Wildgruber, Dogil, and Grodd, (2000), the anterior insula contributes to the coordination of vocal tract movements during singing. An area associated with laryngeal sensations and motor control has been found in both S1 by Grabski et al. (2012) and M1 (motor cortex) by Brown, Ngan, and Liotti (2008) and Brown, Laird, and Pfordresher (2009). Together these areas show a specific body-part somatosensorimotor representation for vocalization (cf. Kleber & Zarate, 2014).

Hierarchical Brain Organization Underlying Vocalization

Based on the work of Simonyan and Horwitz (2011), Kleber and Zarate (2014) distinguish three hierarchical levels of brain activity that control human vocalization (see table 17.1). Only in humans is there a direct connection between the vocalization area in the primary motor cortex (M1) and the brainstem neurons that command phonatory (laryngeal) muscles.

Figure 17.6 represents the hierarchical interactions of the various anatomical structures of the brain referred to in table 17.1 and shows the sensorimotor feedback from the activity of the vocal tract, on the left of the figure, as well as the auditory feedback from vocal production, on the right of the figure (Zarate, 2013, modified from a model proposed by Jürgens [2009]).

Table 17.1.
Hierarchical organization of human brain areas controlling successively more complex aspects of human vocal production.

Vocalization function	Brain area—increasing hierarchical levels
1. Basic level innate nonverbal vocalizations (e.g., crying and laughing)	1. Brainstem and spinal cord regions
2. Initiation of vocalization: control of voluntary utterances	2. Anterior cingulate (ACC) [controls emotional intonation of speech] Periaqueductal gray (PAG) in the midbrain [damage results in mutism]
3. Highest level of vocal control	3. M1 (primary motor cortex) and associated modulatory brain regions (putamen, globus pallidus, thalamus, pontine gray, cerebellum) [damage produces vocal disorders, e.g., stuttering]

Source: After Kleber & Zarate (2014).

Beginning in the lower center of figure 17.6 (white boxes), the vocal motor control hierarchy starts with (1) the generation of complete vocal patterns by the reticular formation and phonatory motoneurons, followed by (2) the next highest level of control, which entails the anterior cingulate cortex (ACC) and periaqueductal gray (PAG), both of which produce vocalizations when stimulated electrically or pharmacologically (Zarate, 2013). The ACC/PAG network has the ability to initiate vocalization and control voluntary utterances. The highest level of vocal control comes from (3) the primary motor cortex (M1; its modulatory brain regions—putamen and globus pallidus and pontine gray and cerebellum—are not depicted), which is responsible for producing learned vocalizations of song and speech.

Somatosensory feedback (dotted arrow, left) from various receptors distributed throughout the vocal tract is processed in the ascending somatosensory pathway (black slanted lines indicate that only selected regions of this pathway are shown) and transmitted to the primary and secondary somatosensory cortex (S1, S2). Auditory feedback (dashed arrow, right) from the vocalization is processed by the ascending auditory pathway (lateral lemniscus and inferior colliculus) and auditory cortical regions (STG/STS). Potential neural regions that integrate sensory feedback processing with vocal motor control include: (A) the PAG, (B) ACC, and (C) the insula (classified as a higher-order associative area).

According to Kleber & Zarate (2014), vocal motor control and feedback develop in three stages:

1. Mapping of auditory and motor process. Auditory feedback is used to establish a relationship between motor commands and sensory consequences and contributes to accurately imitating a target and associated error-correction.

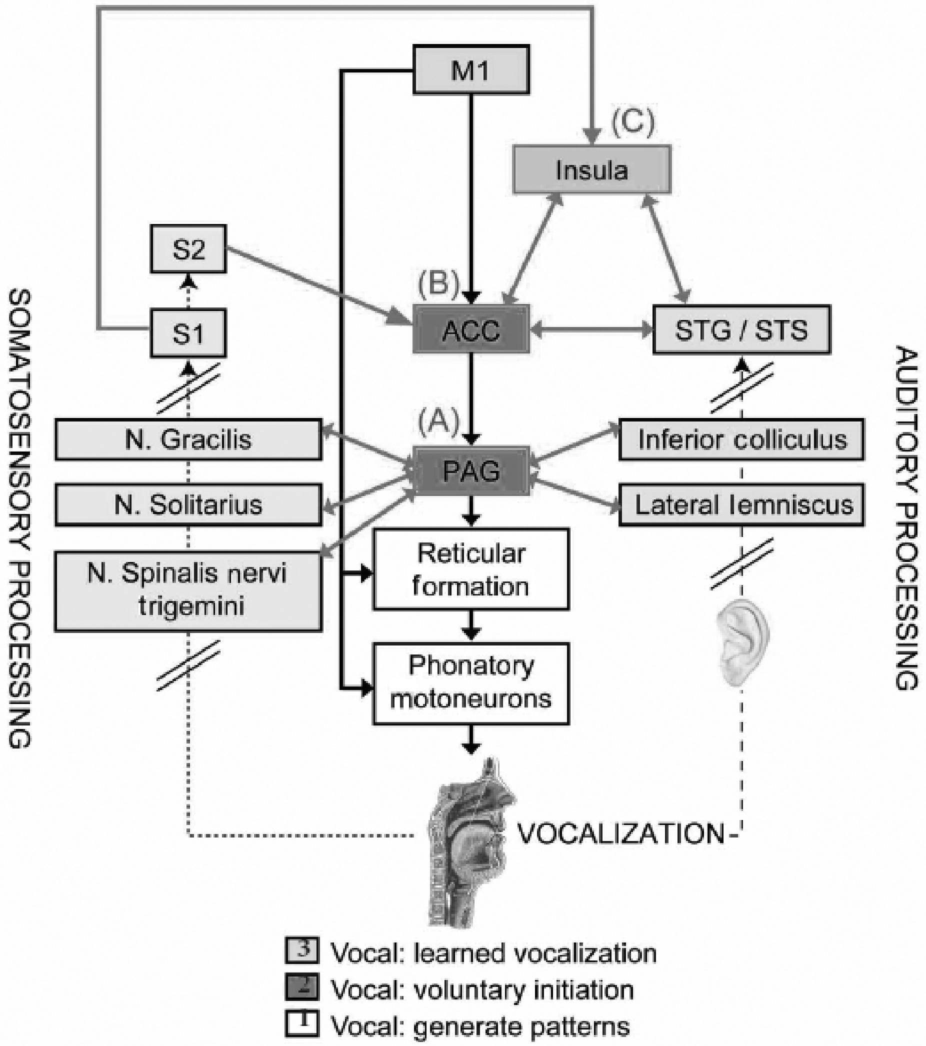

Figure 17.6
Neural networks of vocal motor control (central column), somatosensory (left), and auditory feedback processing (right), and hypothesized regions of sensorimotor control of voice.
Source: Adapted with permission from Zarate (2013, p. 2).

2. Engagement of a feedforward model and somatosensory control system
   (a) Engagement of the cerebellum and premotor areas ("cortical areas that select or prepare motor programs for M1," p. 5) as a feedforward model predicting the current state of the vocal tract components and their sensory consequences. This model can account for eventual acoustic error reduction.
   (b) Engagement of S1, the somatosensory control subsystem and related regions of the cortex, as a somatosensory representation of the learned auditory-motor mapping. Auditory targets can coactivate the corresponding somatosensory targets.
3. Engagement of neural substrates for audiovocal integration for singing
   (a) subcortically, the periaqueductal gray (PAG) for readiness to vocalize
   (b) cortically, the auditory cortex within superior temporal gyrus (STG) and superior temporal sulcus (STS), and anterior cingulate (ACC) are active during speech and singing as compared to perceiving singing.

Figure 17.7 from Zarate (2013) represents the key areas and pathways in the brain thought to underlie the vocal sensorimotor feedback loop. The covert pathway for pitch perception (lowest arrow) includes auditory cortex and inferior frontal gyrus (IFG), while the overt pathway for vocal pitch production (all other arrows) includes intraparietal sulcus (IPS), anterior insula (aINS), anterior cingulate cortex (ACC), and dorsal premotor cortex (dPMC). Figure 17.8, also from Zarate (2013), illustrates the areas sensitive to vocal training. The structures described in table 17.1 and figures 17.6 and 17.7 are required for singing but do not differentiate singing from speech. It is thought that singing as compared to speech recruits a more distributed network, potentially in both hemispheres (Herbert et al., 2015), although the degree of diffuseness and hemisphere specialization may be subject to vocal training. Following Zarate (2013), the primary somatosensory cortex (S1) engages the anterior insula (aINS), while the inferior frontal gyrus (IFG) is not influenced by training. More specifically as represented in figure 17.8, as a function of the amount of weekly vocal practice: activity in primary somatosensory cortex (S1) increases, suggesting a greater reliance on somatosensory feedback with more training and experience; the anterior insula (aINS) can serve a gating function of somatosensory feedback; features within auditory feedback are processed and extracted by auditory cortex (STG/STS) and the intraparietal sulcus (IPS); and task-relevant auditory information is sent to the anterior cingulate cortex (ACC) to adjust vocal output according to the singing task demands. In people with little to no formal vocal training, task relevant auditory information is sent via the aINS to the dorsal premotor cortex (dPMC).

A case report of an avid singer with a right fronto-temporo-insular lesion provides some evidence for dedicated singing and speaking networks (Herbert et al., 2015).[9] Prior to actual

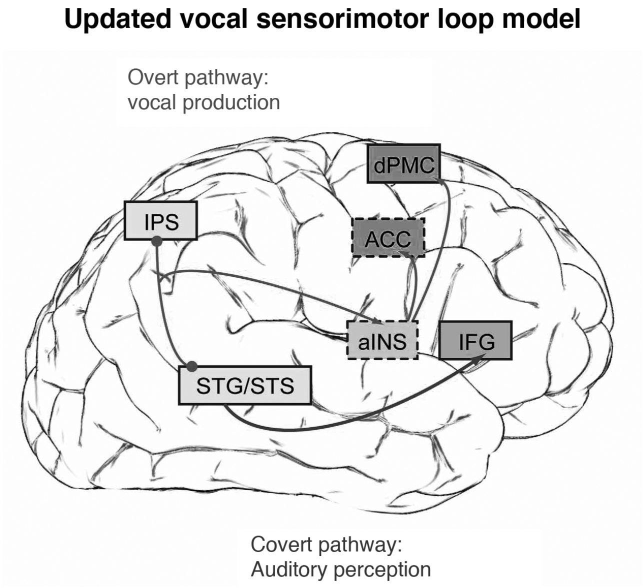

Figure 17.7
The vocal sensorimotor loop model for singing based on Berkowska & Dalla Bella (2009), Dalla Bella et al. (2011) and fMRI studies of Zarate & Zatorre (2008) and Zarate, Wood, & Zatorre (2010).The covert pathway for pitch production (bottom arrow) includes auditory cortex and inferior frontal gyrus (IFG), while the overt pathway for vocal pitch production (all arrows except STG/STS to IFG) is comprised of auditory cortex (STG/STS), intraparietal sulcus (IPS), anterior insula (aINS), anterior cingulate cortex (ACC), and dorsal premotor cortex (dPMC). Brain regions normally hidden in this lateral brain view are indicated in boxes outlined with dashes. IPS and STG/STG refer to auditory processing, dPMC and ACC refer to motor control, and aINS refers to multimodal processing.
Source: Adapted with permission of Zarate (2013, p. 8, figure 3).

surgery, while awake, he underwent direct electrical stimulation (DES) to determine the localization of various functions by activating a small cerebral area for a few seconds.[10] He was asked to perform various verbal tasks that also engaged vision and emotion. Stimulation of the anteroposterior pars opercularis of the right inferior frontal gyrus (IFG_{op}, Brodmann areas 44 and 45, homologous to Broca's area in the left hemisphere) elicited a switch from a speaking to a singing mode.[11] Herbert et al. (2015) propose two independent neural networks relatively specialized for either speech or singing, and "a neurocognitive mechanism allowing an individual to flexibly pass from speaking to a singing mode of speech production" (p. 1402).[12] It was concluded that like persons who are bilingual, experienced singers may develop a dedicated neural subnetwork specialized for production of "melodically intoned articulation of words," which competes with the neural network devoted to

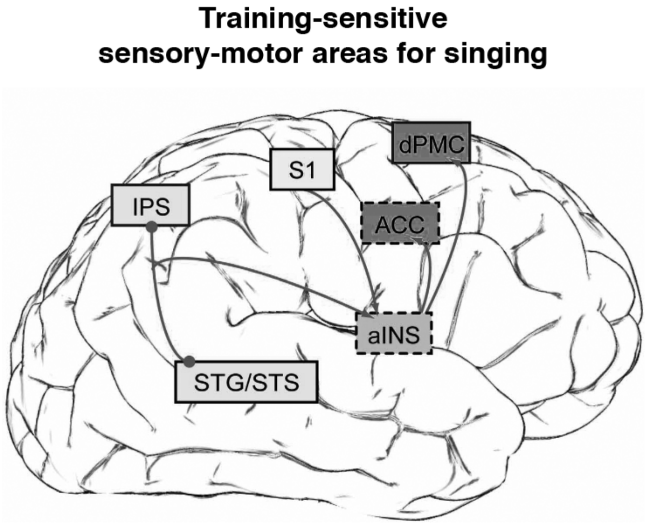

Figure 17.8
Neural substrates for sensorimotor control of singing that are sensitive to the amount of vocal training based on findings of Kleber et al. (2010, 2013), Zarate and Zatorre (2008), and Zarate et al. (2010). Source: Adapted with permission of Zarate (2013, p. 8, figure 4).

language production, and that an inhibitory mechanism enables appropriate use of one over the other (p. 1404).

In contrast to findings regarding the DES-disruption of speaking by singing, Katlowitz, Oya, Howard, Greenlee, and Long (2017) reported an opposite pattern in a professional male vocalist who was undergoing surgery in the right hemisphere to combat severe epilepsy. The researchers carried out two kinds of direct stimulation to a portion of the right posterior superior temporal gyrus (pSTG),[13] applying first electrical stimulation, as did Herbert et al. (though in the frontal lobe), and then focal cooling. In this case, singing rather than speaking was suppressed by the electrical stimulation.[14] It should be pointed out that the study was not conducted with the aim of studying a singing network per se. Taken together, the DES findings of Hebert et al. (2015) and Katlowitz et al. (2017) are consistent with the idea of two competing networks for singing and speech. Özdemir, Norton, and Schlaug (2006) supported the notion of distinct neural correlates for singing and speaking as well as overlap; however, a decade later, Belyk and Brown (2017) have hypothesized “a single vocal system in the human brain that mediates all the vocal functions of human communication and expression, including speaking, singing, and the expression of emotions” (p. 182). The difference in positions may be partially semantic.

Brain Imaging

The larynx is of key importance to singing and speech. Through an fMRI study of vocal and nonvocal laryngeal engagement, Brown et al. (2008) mapped the area in the human motor cortex that controls the intrinsic muscles of the larynx. They named the area *the larynx motor cortex* (LMC) as it continues to be known (e.g., Belyk and Brown, 2017).[15] Participants in the study had also shown engagement of the LMC in harmonic and melodic discrimination tasks (Brown & Martinez, 2007) and singing tasks (Brown, Martinez, Hodges, Fox, & Parsons, 2004). The LMC activation in auditory perception, melodic discrimination, and vocal production suggested its role in audiomotor integration, a role that is characteristic of the postulated mirror system (Rizzolatti & Craighero, 2004) and adds further to the LMC significance. The mirror neuron system has been heralded as a key aspect of the power of music, through imaging oneself singing music to which one is listening (Overy & Molnar-Szackacs, 2009; see also Miller, 2016). Based on the mapping of the LMC and additional empirical and theoretical work, Belyk and Brown (2017) proposed an integrated vocal-motor system underlying all vocal behavior. The proposal is compatible with Brown et al.'s (2004) hypothesized network supporting vocalization in general (sung or spoken) and is also compatible with Kleber and Zarate (2014) although emphasis on certain features differs.

Because song entails lyrics, brain imaging research assists in distinguishing areas specialized for nonverbal versus verbal components by contrasting brain activity for tasks involving only speech, only melody (sing on a syllable), or melody plus lyrics. Comparing trained and untrained vocalists can add to the picture of how systems become more differentiated with experience. The brains of musicians have been characterized by increased gray matter and cortical thickness in selective areas, as well as altered white matter organization (e.g., corpus callosum) (Hyde et al., 2009). Several recent studies have focused on experience-dependent structural plasticity of vocalists.

Halwani, Loui, Rüber and Schlaug (2011) compared magnetic resonance images of professional singers, professional instrumentalists, and nonmusicians. Specific focus was placed on the arcuate fasciculus (AF), the white-matter tract connecting regions of the temporal and frontal lobes. The images revealed that vocalists had a larger left hemisphere tract volume than instrumentalists. Because singers as compared to instrumentalists produce words at the same time as producing melody, extra language practice might account for the larger AF in the left hemisphere of singers. Singers, however, had lower fractional anisotropy (microstructure) measures of the AF, and the anisotropy decreased with years of vocal training. The reduced anisotropy, generally taken as an adaptation arising from experience, was thought to reflect a reliance on increasingly complex integration of feedback and feedforward systems required of virtuoso performance levels.

Using voxel-based morphometry, Kleber et al. (2016) showed that classical singers as compared to participants without vocal training showed increased right hemisphere gray-matter volume in four areas: ventral primary somatosensory cortex (larynx S1), adjacent rostral supramarginal gyrus (BA40), secondary somatosensory cortex (S2), and primary auditory cortex (A1). Of key importance is that vocalists who began training earlier in life (but after the age of fourteen years) had increased gray-matter in right S1 and the supramarginal gyrus. The authors note that this contrasts with experienced performers of musical instruments, who show effects of training at earlier ages, and they also note that the age of fourteen years coincides with the plateau in speech motor development. One might look at this from the point of view of closing the window on a sensitive period for speech motor development and opening a window for singing motor development.

Kleber, Veit, Birbaumer, Gruzelier, & Lotze (2010) found in an fMRI study that experienced opera singers compared to nonsingers showed increased blood-oxygen-level-dependent (BOLD) response in primary somatosensory (laryngeal and mouth representation) and parietal association areas as a function of accumulated practice, thus reflecting better kinesthetic control of the vocal production mechanisms. Zarate and Zatorre (2008) observed enhanced auditory activation of the intraparietal sulcus (IPS) and dorsal premotor cortex (dPMC) when trained and untrained singers were asked to retain the pitch of the note they were singing while presented with erroneous auditory feedback. They suggested that the IPS may assess the size and direction of the pitch shift, while the dPMC may associate this information with plans for compensatory motor adjustments. That persons without vocal training showed more activity in the dPMC than did trained vocalists possibly reflected a less efficient motor planning mechanism. Singers recruited different components of the dorsal auditory stream—posterior auditory cortex (STG/STS), anterior cingulate cortex (ACC) and anterior insula (aINS)[16] (cf., Zatorre & Zarate 2012, and also figure 17.8 above).

Because of the possible artifacts arising from head movements while singing or speaking, and for purposes of distinguishing motor from imagery processes, researchers have often used covert rather than or in addition to overt singing and speaking tasks while participants undergo neuroimaging (e.g., Callan et al., 2006). Zatorre and Halpern (2005) reviewed evidence that covert paradigms (involving imagining rather than actually carrying out an activity) engaged neural activity that typically underpins overt musical activity, including singing (see also Belyk & Brown, 2017; Brown et al., 2008; Kleber, Birbaumer, Veit, Trevorrow & Lotze, 2007). Using this paradigm, Wilson, Abbott, Lusher, Gentle, and Jackson (2011) tested participants representing three levels of singing expertise, which also coincided with their level of pitch accuracy. In the singing task, participants covertly sang the beginning of a familiar folk song. In the word task, the participant covertly generated as many words as possible beginning with a visually presented letter. When singing, expert singers showed less activity in the right hemisphere and less overlap with the traditional language areas than did nonexpert singers—a result suggestive of an adaptation based on experience.

To summarize this section, singing entails a complex sensorimotor feedback system to support control of an extensive vocal apparatus for both gross and fine motor coordination. Both the anatomical and the neurophysiological systems underlying singing share many features with systems underlying speaking. Yet singing entails different constraints and demands in its simultaneous coordination of production of precise melodic and phonetic information. At least for vocalists who have received extended training, there appears to be a "singing network" distinct from and perhaps in competition with a speaking network. Thus, while Belyk and Brown (2017) focus on the general functionality of the LMC, studies of highly trained compared to untrained or less-trained vocalists have revealed larger left-hemisphere arcuate fasciculus and reduced fractional anisotropy (Halwani et al., 2011); increased right hemisphere gray matter in somatosensory larynx S1, SMG, somatosensory S2, and primary auditory cortex, with increases in S1 and SMG varying with years of training after age fourteen (Kleber et al., 2016); increased BOLD response in somatosensory S1 and parietal association areas (Kleber et al., 2010); more left hemisphere activity in covert singing and less overlap with the traditional language areas (Wilson et al., 2011). Vocal training leads to more refined networks for audiomotor integration, more focal activation in the ventral sensorimotor and subcortical motor areas important for kinesthetic motor control, and more specialized circuits in the left hemisphere when singing lyrics. The evidence that cortical laryngeal representation increases with vocal training after the age of fourteen years leads to speculation regarding a critical period for development of motor control of singing that follows after a critical period for the development of sensorimotor articulatory competence underlying language acquisition.

Development

Early Years

Every child naturally acquires the ability to sing early in life, around the same time as language is acquired. As with language, the songs and music heard during early childhood influence what the infant or child sings. While thousands of studies have been conducted on the acquisition of spoken language, relatively few have been conducted on the acquisition of singing. The few musically oriented analyses of infant and toddler vocalizations reveal the potential richness of this endeavor.

Early vocalizations The sounds of early infancy have been typically regarded as prelinguistic rather than premusical. Control of phonation (pitch control) appears between one and four months, exposure to language leads to production of basic canonical syllables between five and ten months, and the utterance of first words around the age of ten to fourteen months (Nathani, Ertmer, & Stark, 2006). Yet, as recently argued by Costa-Giomi and Benetti (2019), exposure to singing and music could equally lead to the imitation of musical elements of the prevailing culture. Several researchers holding a similar view have reported infant imitation of melodic fragments (Reigado, Rocha, & Rodrigues, 2011; Tafuri & Villa, 2002), although there is very limited evidence of infants' ability to imitate individual pitches (Kessen, Levine, & Wendrich, 1979). However, pitch analysis of the infant child by developmental researchers Hanus Papoušek, and Mathilde Papoušek (1981) revealed remarkable fidelity, including sensitivity to harmonic relations. Recently, the invention of a lightweight wearable device (LENA, *L*anguage *EN*vironment *A*nalysis), which will record audio for sixteen consecutive hours, has facilitated the study of vocalization by the infant when alone. The analysis by Benetti (2017; Costa-Giomi & Benetti, 2019) of such vocalizations of a fifteen-month-old infant revealed several striking imitations of music and singing heard briefly earlier in the day. The evidence was validated in an experiment in which adult listeners were asked to choose which of several songs the infant was singing. The musical nature of this infant's private vocalizations is consistent with recordings and parents' observations of their toddlers (eighteen to thirty-five months) in their cribs at bedtime (Sole, 2017). Singing examples ranged from vocal exploration, to singing known melodies, to free flowing singing, to wind down and relax (a concept from Young, 2006).

Infant-directed singing Inspired by research on infant-directed speech (motherese), Sandra Trehub initiated seminal explorations of the reciprocal relation between caregiver and infant in singing (e.g., Bergeson & Trehub, 1999, 2002; Trehub & Trainor, 1998; Trehub, Unyk, & Trainor, 1993, see also Trehub, chapter 7 this book). With respect to development of singing, therefore, the focus is not only on the progression of production of sound patterns that come under the control of the growing child, but also on infant-directed singing (IDS), infant responses to those songs, and the impact of the infant responses on the adult singer. Infant-directed (ID) singing shares with ID speech more characteristics of higher pitch and slower tempo than adult-directed (AD) counterparts (Fernald, 1984), although cross-cultural universal features remain to be determined (Mehr & Krasnow, 2017). Infants, even newborns, have shown preference for ID over AD singing (Masataka, 1999; Trainor, 1996) and for ID singing over ID speech (Costa-Giomi & Ilari, 2014; Ilari, 2005; Tsang, Falk, & Hessel, 2017). ID singing delays infant stress response longer than does ID speech (Trehub, Ghazban, & Corbeil, 2015; Corbeil, Trehub, & Peretz, 2015). Evidence for such discrimination indicates that infants older than seven months are able to form some abstract representation of ID singing as distinct from ID speech or AD speech or song—a significant perceptual-cognitive achievement. Yet infants do not always attend more to ID singing than ID speaking (e.g., Trehub, Plantinga, & Russo, 2016). Their attention partially depends on the extent to which the ID speaking or ID singing sounds happy (Corbeil, Trehub, & Peretz, 2013). While mothers initially use ID singing to provide emotional support for their infant, later they become "singing mentors" to develop communication skills such as turn-taking and language (Trehub & Gudmundsdottir, in press).

Falk (2011) explored the differences in ID speaking and singing by comparing the melodic contours for three languages (French, German, and Russian) for play songs and soothing songs.[17] Contours were classified as linear, bell-shaped, U-shaped, or sinusoidal depending on number of maxima and minima, in accordance with the method of Cordes (2005), and in terms of several other related parameters identified by Katz, Cohen, and Moore (1996) and Papoušek (1996). Playsongs and ID speech had common contour features across all languages, but soothing songs showed distinctions across languages and within languages between singing and speaking. There were stronger differences in tempo, with ID singing being slower. Nakata and Trehub (2011) point out the challenges of cuing ID singing from contour, given that in singing a familiar melody, such as a nursery rhyme, exaggerated contour would destroy the identity of the melody. In comparing the ID singing of mothers and the non–ID singing of nonmothers of the song "Twinkle, Twinkle Little Star," Nakata and Trehub found less tempo variation for mothers than nonmothers, but greater dynamic range. Further, dynamic range was more highly correlated with pitch height for the ID versus non–ID singing. The authors suggest that because melodic contour is constrained in ID singing, mothers know intuitively to correlate intensity cues with contour (thereby cuing contour differences).

Turn-taking also characterizes language development, and infants engage in turn-taking when presented with ID singing. Van Puyvelde, Loots, Gillisjans, Pattyn, and Quintana (2015) reported that these turns of both mother and infant echo either the fundamental frequency of the final tone of the utterance or a harmonic of that frequency. While evidence was obtained in both Belgium and Mexico, further data from independent research groups are needed to verify this example of a highly sophisticated aspect of reciprocal vocal interaction within the infant-caregiver dyad.

While singing by new mothers is not required for effective caregiving, Ilari (2005) reported that 92 percent of one hundred mothers in Canada interact musically with their infants through singing. A review by Mehr and Krasnow (2017) supports the likely universality of this parental behavior. As shown in a qualitative study, mothers residing in New York find singing to their infants rewarding on many levels (Pixley, 2015). Singing to infants enabled mothers to connect with and engage their infants and to regulate both the infants' and their own affect, provided a means for enhancing transmission of language and culture to their infant, and offered an opportunity to reflect upon different periods of their own lives, from adulthood to childhood.

Stages of singing development Longitudinal studies of infant singing and quasi-experimental studies with children have led Stephanie Stadler Elmer (2011) to emphasize that singing development is by no means a simple straightforward process. From her perspective, prolongation of vowels is a first prominent characteristic of most singing (as compared to their shorter duration in speech).[18] Secondly, singing in children is associated with playing with their sound, and usually involves body motion. Movements—typically walking or dancing—are often metrically synchronized with vocal sounds and anchor a regular pulse; whereas breathing movements determine the song's phrases, thus altogether framing the temporal units. Third, in general, singing is often used to create an emotion in oneself or another. Stadler Elmer (2015a, 2015b) conceptualizes singing of songs as a universal cultural means—or as play or ritual—to regulate emotional states from early on in life. But culture must be considered: children all over the world acquire the rules or conventions of singing songs as practiced in their cultural environment. While cautioning against specifying age-ranges, she suggests on the basis of her longitudinal studies that children's singing acquisition exhibits a developmental sequence involving seven stages:

1. Beginning co-evolution of innate expressive predispositions with the social environment (emphasis on infant-parent dialogues, monologues, vocal play, imitation);
2. Deferred imitation, emergent rituals, and extended vocal play;
3. Intentions to produce singing-like or speech-like vocalizations (appreciating the functional differences of speech and song);
4. Sensorimotor strategy: auditory-vocal coordination to produce song fragments or entire songs (lack of understanding of conventional rules);
5. Generalizing examples, idiosyncratic song repertoire, and idiosyncratic singing rules (violations to cultural conventions, as reflected in invented and spontaneous songs);
6. Implicit integration of conventional rules for song singing (growing song repertoire and implicit understanding of song conventions of the culture);
7. Beginning reflection of actions, means, symbols, and concepts (singing and music-making are deliberate tools to manage affective states and participate as a member in a group).

Her perspective places music as central to singing development and contrasts with other stage approaches that assume the primacy of language in the initial stage followed by the child's focus on rhythm, then contour, and lastly key stability (for review, see Welch, 1994). The controversy between these two positions may be partially resolved by consideration of the affordances of the home environment of the child, specifically the presence of music and singing. Forrester and Borthwick-Hunter (2015) provide a review of longitudinal studies of early musicality, many of which focus on singing and help to understand the importance of situational context on development.

Multimodality of Singing

Singing entails more than the auditory domain due to the intrinsic (e.g., required articulatory motion to form vowel sounds) and ancillary (e.g., swaying of the body, eye-widening) motor involvement (Costa-Giomi, 2014). Voice training often entails learning to suppress extraneous (ancillary) facial motions that naturally accompany singing. As Stadler Elmer (2011) mentioned, singing in children typically accompanies motion of the body, as in play. In infant-caregiver interaction, rocking an infant in time with the music associates kinesthetic information with singing for both infant and caregiver. Bodily motion associated with singing provides a visual dimension to singing. Trehub et al. (2016) explored the role of face-to-face versus out-of-view presence of an infant on the degree of emotionality and smiling of mothers in their ID singing. Young adults rated emotionality and smiling of mothers (shown in a video) while singing or talking with the infant, who was in or out of view of the mother. The duration of mothers' smiling was higher with the infant in view, and the average duration while singing with the infant in view exceeded that for speaking. This study and several related follow-up studies indicate that visual cues from the infant influence the mother's engagement in infant-directed singing. Whereas infants are sensitive to cross-modal correspondences in ID singing (Trehub, Plantinga, Brcic, & Novicki, 2013), the visual information of the infant in a sense controls the degree of correlated audiovisual information that the mother provides during ID singing.

Countryman, Gabriel, and Thompson (2016) recorded, described, and categorized the spontaneous vocalizations of children (ages three to twelve years) during play in childcare centers and school playgrounds. Physical play movements and vocalization typically co-occurred. Longitudinal or age cross-sectional studies of the spontaneous activity of children while singing would fill a gap in current knowledge regarding the natural trajectory of the pairing of singing and motor activity. Research with adults has, however, explored some complex multimodal aspects of singing with respect to both perception and production.

Thompson and Russo (2007) studied the dynamics of facial and head motion during singing of musical intervals (ranging from one to twelve semitones). The singers were vocalists who had received many years of training on piano but no formal vocal training. The separation between their lips, extent of eyebrow raising, and head position were all correlated with interval size. When participants viewed only the video images of the singers, their judgments of the size of the sung intervals was nearly perfectly correlated with the actual size of the sung (but unheard) intervals. The results suggest that visual information of facial motion can serve as cues for information about a sung melody. A follow-up study used eye-tracking to show that viewers directed more attention to the mouth than the eyes, especially under conditions of reduced audio information (Russo, Sandstrom & Maksimowski, 2011). This finding can be understood in terms of the relative informativeness of mouth and eye areas: the amount of displacement is greater for mouth opening than eyebrow raising. Increasing loudness decreases reliance on the mouth for information and frees resources to extract other information. The eye area potentially provides emotional information that is less relevant to the task at hand.[19] Gaze toward the eyes also increased for the five most consonant intervals and with interval size. Russo et al. (2011) note that it is easier to sing consonant than dissonant intervals (see also González-García, González, & Rendón, 2016). The eye-tracking results showed some differences between the two singers, and it can be speculated that even fewer effects might have appeared with trained vocalists because mouth opening may be less correlated with pitch height in vocalists who are classically trained.

A further study of estimation of vocalized interval size, conducted by Abel, Li, Russo, Schlaug, and Loui (2016), used recordings of point-light sources to convey facial movement, presented either congruently or incongruently with the sung intervals. Judged size was highly correlated with audio, visual, and congruent audiovisual (AV) information, with video producing much lower correlations. Those with music training showed a greater reliance on the audio information in the incongruent AV condition, and those with early onset of training were even more focused on the auditory dimension. The findings suggest that persons lacking training or starting training later in life focus more on the visual sense for information about sung intervals, while training heightens the significance of the auditory modality. This study (Abel at al., 2016) emphasizes the significance of early training in mastering skills to most effectively process the various modalities of singing information.

The vocal pedagogy for classical singing aims to enable a singer to produce a desired vocal quality across the entire vocal range—that is, without breaks in moving up and down the frequency range. This is a challenge due to the design of the larynx and vocal tract, which produce natural, uneven patterning of resonances across the vocal range: certain fundamentals and harmonics are more easily produced than others. Through practice of legato (continuous) singing from note to note, or through practice singing glissandi up and down, the vocal student learns to coordinate breath support and muscles controlling the shape and properties of the vocal tract so as to achieve a seamless melodic flow across the entire vocal range from one register to another. In accomplishing this task, the trained vocalist learns to suppress natural tendencies to move parts of the body (mouth, lips, limbs, or torso) that are unnecessary for creating a pleasing sound, although they would be natural for children and untrained singers to carry out. For example, it is not necessary to look up and stretch one's neck for increasingly higher notes, though it may be natural to do so. Such extraneous movements can alter the configuration of the vocal tract and change the quality of the voice for the worse (Barnes-Burroughs, Watts, Brown, & LoVetri, 2005; Barnes-Burroughs et al., 2007).

Multiple Singing Skills

At first thought, singing might be regarded as a single behavior, but many skills are associated with singing; these include matching of individual pitches and pitch patterns, being able to cover a wide frequency range, singing a familiar song, learning a new song, and creating a song. All of these have been investigated individually, as shown in table 17.2.

AIRS Test Battery of Singing Skills The *Advancing Interdisciplinary Studies in Singing* (AIRS) *Test Battery of Singing Skills* (ATBSS) acquires data on many singing skills and enables testing across the lifespan, levels of musical training, and cultures (Cohen, 2015; Cohen, Armstrong, Lannan, & Coady, 2009).[20] The ATBSS aimed to advance understanding of singing development across the lifespan by obtaining sufficient data to explain singing development as a function of innate and universal factors, individual differences, and cultural influences. In addition to tests of different singing abilities, the ATBSS also included several language components, because singing has both musical and linguistic components, and because of the value of tracking singing and language development simultaneously. The long-term vision for the ATBSS necessitated the translation of the test into prominent languages of the world, the creation of a version for children, and development of an automated version that could improve standardization of procedure and acquire potentially unlimited data over the Internet. The first studies carried out using the ATBSS revealed a rich source of data, seemingly more than any one researcher could thoroughly analyze in a lifetime. The value of the data from individual studies grows, as data accumulates from multiple studies. Making all data accessible in a digital library would allow researchers infinitely numerous comparisons focusing on influences such as age or culture in performance of certain components of the ATBSS. A further goal of the ATBSS is to provide norms for different ages, genders, language groups, and cultures for voice range, pitch accuracy, sensitivity to tonality, learnability/memory, creative ability (song completion and song creation), and song style preferences. At present the ATBSS is a research tool for obtaining such data under standardized conditions and in the context of several verbal aspects of phonemic accuracy, phonemic learnability, average speech frequency, verbal fluency, and the ability to make up a story.

Table 17.2.
Singing skills and a sampling of their independent investigation in children.

Singing skill	Study
Vocal range	Flowers & Dunne-Sousa (1990)
	Kim (2000)
	Moore (1991)
	Rutkowski (1990)
	Welch (1979, review)
Pitch (or pitch pattern) matching	Apfelstadt (1984)
	Demorest (2001)
	Demorest & Clements (2007)
	Flowers & Dunne-Sousa (1990)
	Geringer (1983)
	Green (1990)
	Kim (2000)
	Nichols & Wang (2016)
	Sims, Moore, & Kuhn (1982)
	Stadler Elmer (1990)
	Trollinger (2003, 2004)
	Wolf (2005, 2012)
	Yarbrough, Bowers, & Benson (1992)
Singing a familiar song	Adachi & Carlsen (1995)
	Adachi & Trehub (1998)
	Beck, Rieser, & Erdemir (2017)
	Chen-Hafteck, van Niekerk, Lebake, & Masuelele (1999)
	Davidson (1985)
	Nichols & Wang (2016)
	Mang (2002, 2006)
Learning an unfamiliar song	Leighton & Lamont (2006)
	Stadler Elmer (2000, 2001)
	Rutkowski (1990)
	Rutkowski & Miller (2003)
Creating of an original song	Adachi & Trehub (1999, 2011)
	Barrett (2006)
	Cohen (2011c)
	Davidson (1985)
	Davies (1992)
	Mang (2005)
	Stadler Elmer & Hammer (2011)
	Werner (1917)

Studies using the ATBSS have shown superior skills of girls over boys in Brazilian and Latino (US) communities with respect to accurate vocalization of short melodic components (Ilari & Habibi, 2015). This could, however, arise from different cultural expectations, and clearly such research is the tip of the iceberg. Research in Estonia, which focused on analysis of the improvisation (song completion and song creation), showed that by the age of four years, most children could create a song with rhythm, melody, and ending on the tonic (characteristic of the Western musical canon) (Raju, Välja, & Ross, 2015). That Estonia is known as a singing culture provides an explanatory context for the level of early expertise observed. A comparison of Chinese-born and Canadian-born university students at a Canadian university revealed the interference of foreign lyrics on learning the melody of a new song (Cohen, Pan, Stevenson, & McIver, 2015).

Focusing on improvisations obtained through the automated version of the ATBSS (Pan, Liu, & Cohen, 2012), Ellis et al. (2017) applied dimensional reduction and cluster analysis to wordless melodies produced by over seventy Canadian adults and revealed the adherence of the majority to Western tonality. Three relatively discrete clusters of improvisation style/ability emerged related to phrase structure (use of repetition, repetition with variation, and phrase symmetry) and rhythm (use or not of standard metric patterns). The vocal improvisations were coded by ear on nineteen structural dimensions drawn from the "CantoCore" musical classification scheme (Savage, Merritt, Rzeszutek, & Brown, 2012), which in turn was based on the Cantometrics of ethnomusicologist Alan Lomax (1968, 1976).

Potentially biased samples A challenge for researchers in the study of adolescent and adult singing is the willingness of participants to volunteer. Anxiety about singing is common, even among children (Raju & Ross, 2012). Researchers of embarrassment in the United States and Australia have often used singing as a means of inducing embarrassment (Brown & Garland, 1971; Drummond et al., 2003; Drummond & Su, 2012; Gerlach, Wilhelm, & Roth, 2003; Hofmann, Moscovitch, & Kim, 2006). Studies of embarrassment have examined responses during the act of singing (of, e.g., an emotional ballad, the national anthem, or a nursery tune) or in viewing a recording of one's own singing. Measures of blushing, heart rate, respiratory sinus arrhythmia, skin-conductance, and self-reported levels of embarrassment have shown differences when compared to other tasks such as speaking or reading. Notably, these studies have entailed persons of Western culture and may not generalize to non-Western cultures or to sub-cultures of Western society in which active engagement in singing is a normal part of everyday adult life. A psychometric singing experience scale (SE) developed by Gick and Busch (2015) includes twenty-three rating-scale items that provide a measure of the extent to which someone self-identifies as a singer (Busch, 2010). This instrument may be useful as a research tool for characterizing a participant group (e.g., students in various educational and cultural settings) in a singing research study.

Gender and Hormonal Effects on the Singing Voice

The voices of prepubescent female and male children are very similar. During puberty the voices of both females and males change along with sex-specific hormonal changes (Pedersen, Agersted, & Jønsson, 2015). According to a review by Kadakia, Carlson, and Sataloff (2013), the hormones during puberty cause a drop of one-third of an octave in the female voice and of about an octave in the male voice. These authors also elaborate on the negative effects on the female voice of hormones associated with the menstrual cycle (see also Khare, 2016, for a similarly focused review). *Negative* in this context refers to greater difficulty in reaching high notes and altered (reduced) vocal clarity. Kadakia et al. (2013) also refer to "the most drastic changes" during menopause, when levels of estrogen and progesterone fall and in some women androgen levels increase and lowered voices result. Nevertheless, a recent double-blind study that compared the same professional vocalists at three time points during three months in a placebo condition (induced by an oral contraceptive pill) and at three points in a normal hormonal cycle found few significant effects in pitch accuracy and vibrato rate, and then only in the placebo condition (Lã, Sundberg, Howard, Sa-Couto, & Freitas, 2012). All authors emphatically propose the need for much more research in this area.

Dramatic effects of hormonal influence on singing are associated with the adolescent male voice. Freer (2015) interviewed young men between the ages of twelve and eighteen in four European countries. One third of the men were continuing singers, one third had stopped singing, and one third had never sung. Using a Grounded Theory approach, entailing open, selective, and theoretical coding, he found results consistent with a theoretical view of Possible Selves (Creech et al., 2013). The idea is that identity arises in response to a combination of social cues, and that one behaves in ways that are congruent with one's hoped for or expected self. The conception of a possible self may develop sequentially, through initially discovering personal strengths (Hock, Deshler, & Schumaker, 2006). Boys who had reason to imagine themselves as singers, either because of role models or because of support from peers, teachers, or others, tended to continue singing, while those whose self-image and sense of competency did not include singing tended never to sing or to discontinue singing. This study suggests that the lack of interest of adolescent males in singing is far from innate and is greatly influenced by social factors that are under control of educational institutions as well as families and other institutions, all of which in turn influence adolescent peers. Attitudes to singing are very much influenced by particular schools and teachers and not by culture. The top reason given for withdrawing from choir was that choral singing is not masculine. Other reasons given were displeasure with their changed voice, the lack of male peers, the lack of focus on individuality, and traumatic loss of their child voice.

Older Years

Although the ability to sing continues throughout life, little research has been directed to singing in older adults, and much remains to be discovered about the trajectory of singing ability in senior years. Normal aging is associated with a common decline in high-frequency hearing, known as *presbycusis*. There are also age-related changes associated with the larynx known as *presbylarynges*, and age-related changes to the voice, or *presbyphonia* (Whited, Keeler, Scearce, & Cohen, 2015). According to Whited et al. (2015), to whom readers are referred for a detailed review of this topic, loss of hyaluronic acid, an increase in collagen, and a decrease in collagen organization, all associated with aging, can affect viscoelasticity, which, in turn, has implications for vocal cord physiology and function. The decline in muscle mass of the body in general can begin as early as the age of twenty-five years and can also be seen in the thyroarytenoid muscle. However, physical fitness can combat decline of muscle mass.

Several studies have suggested that engagement in singing by older persons leads to speaking voices sounding significantly younger than is the norm for older voices. Older speaking voices have been judged as hoarse, breathy, shaky, raspy, and weak (Prakup, 2012). The average pitch of the speaking voice changes with age and gender. For males it begins to rise in old age, while for females, there is a lowering around the time of menopause (Linville, 1996). Lortie, Rivard, Thibault, & Tremblay (2017) explored voice parameters representing three levels of frequency of singing in healthy nonsmoking adults (twenty to ninety-three years old). For frequent singers, stability of pitch and vocal amplitude of the speaking voice did not decline with age as compared to less frequent singers. Singing engagement was a protective factor against changes in the speaking voice. Longitudinal studies are needed to determine how singing experience changes the voice with age.[21] The importance of singing in the lives of older adults has led to the commercial development of a computer application (SingFit) for selective cuing verbal, melodic, and harmonic information of a song to support singing. Reid, Rakhilin, Patel, Urry, and Ayanna (2017) conducted a study with older adults showing daily compliance over several weeks with singing "homework" in accordance with a SingFit playlist program; this suggests the applicability of SingFit technology for future research in addition to its current applications in individual and group settings.

Vocal Accuracy

No topic in singing research has drawn as much attention as vocal accuracy. Questions of interest focus on general ability (is vocal accuracy normally distributed, or is the distribution bimodal, implying that there are simply "singers" and "nonsingers"?), changes with age, age norms, and measurement. Dalla Bella, Giguère, and Peretz (2007), who asked people to sing two familiar songs, reported that most people were on average accurate within a semitone for each note. They concluded that singing accurately was a normally distributed ability. In line with Dalla Bella et al. (2007), Pfordresher and Larrouy-Maestri (2015) emphasize the importance of thinking of singing ability as a continuum.

Many people have a lower opinion of their own singing capacity than the continuum view would suggest (Cuddy, Balkwill, Peretz, & Holden, 2005; Knight, 2000, 2011; Welch, 2017; Whidden, 2008; Wise, 2009; Wise & Sloboda, 2008). Pfordresher and Brown (2007) found that 59 percent of participants agreed with the statement, "I do not think I can accurately reproduce melodies by singing." Such negative self-assessments often stem from an early experience—for example, a choir director's instruction to mouth the words rather than to sing with the others (Welch, 2016).[22] Welch (2017) conceptualizes a three-dimensional space of singer-identity with axes representing degree of singing competence, negative-positive self-concept, and musical/sociocultural contexts. He notes that personal factors such as age, developmental phase, gender, ethnicity, biography, self-concept, and emotional state contribute to the placement of the individual in this space.

Drawing on a concept from statistics, Pfordresher, Brown, Meier, Belyk, and Liotti (2010) distinguished between pitch accuracy and precision, whereby *accuracy* (which is typically measured in studies of pitch accuracy) refers to an average error, while *precision* (not usually measured) refers to a consistent error. Performance of participants, all of whom had no music training, showed lower precision than accuracy scores. Moreover, precision but not accuracy predicted self-assessments of pitch accuracy. In addition, persons who were inaccurate were generally imprecise, while the reverse was not necessarily the case. The authors argued for the importance of measuring precision in addition to accuracy in singing assessment.

Regarding the view that pitch accuracy improves with age, Demorest and Pfordresher (2015) compared data from participants of three different age groups who carried out the same tasks, referred to as *single*, *interval*, and *pattern pitch*. There was improvement in pitch accuracy between kindergarten and middle school; however, the college-aged adults performed as poorly as the kindergarten children, when collapsing over the three kinds of tests. Demorest and Pfordresher (2015) suggested that such a decline could arise from lack of use. Thus, the data did not support a hypothesis that singing improves up through early adulthood, although continuous training would likely lead to improvement. Unimpressive adult results compared to those of children were also found by Beck, Rieser, and Erdemir (2017). Similar questions arise regarding the development of voice range with age.

While studies of vocal accuracy typically focus on solo singers, choral singing with and without accompaniment (a capella) places additional demands on tuning accuracy. Early research in choir acoustics has been reviewed by Ternström (2003). Tuning may be influenced in certain genres to preserve consonance (small ratios) or cultural norms. For example, in certain Lithuanian songs, the distance between notes of a scale, as measured by Ambrazevičius (2015), may systematically expand or contract over the course of the piece, which would entail considerable knowledge on the part of the performers. Factors affecting dynamic control of a choir have been recently reviewed by Titze and Maxfield (2017), who also relate individual voice range profiles to profiles for a choir.

Tests of vocal accuracy Measurement of vocal accuracy can be accomplished aurally with a good ear (and a keyboard for comparison, in the absence of absolute pitch) or through computer analysis. Computer algorithms, however, can produce inaccurate solutions (e.g., selecting $2f_o$ rather than f_o), and guarding against this typically entails human involvement at some stage (e.g., Devaney, Mandel, Ellis, & Fujinaga, 2011). However, with continuous improvements in technology, automated analysis may not be far off, as proposed by Demorest et al. (2015). A high correlation between a computer-analyzed and expert judges' score of overall accuracy was obtained in one careful study entailing a sophisticated semi-automatic computer analysis system and eighteen8 expert judges (Larrouy-Maestri, Lévêque, Schön, Giovanni, & Morsomme, 2013). Ratings correlated significantly with errors of frequency between adjacent notes as well as erroneous key change during the song (modulation). These results support methodologies that rely on two or three judges.

Two subjective rating scale measures used commonly for children's ability to sing a taught song are Rutkowski's (1990) *Singing Voice Development Measure* (SVDM) and Welch's (1998) revised model of *Vocal Pitch Matching Development* (VPMD).[23] Each begins with the assumption that young children attend first to the verbal rather than the musical aspects of a song. Such an assumption may be appropriate in the context of school, where reading has such a priority. The SVDM relates increasing voice range with increasing level of singing voice development, specifically designating the fifth (highest) level, the "Singer" level, as consistently being able to sing a B_4 or higher. The SVDM measures the use of the singing voice, and not accuracy of intonation. The VPMD identifies four levels of increasing dominance of melodic over text elements, increasing reliance on a single as opposed to multiple reference pitches, with the first two stages including aspects of improvisation. Both tests recognize that a limited voice range prevents accurate pitch production, if tones of the melody are outside the voice range. Mang (2006) used both tests to assess singing skill of children of seven to nine years of age in Hong Kong and found a correlation of .685 between scores of two judges—a result suggestive of both common and unique features of each test. The test results were helpful in revealing superior singing skills in the children who were unilingual Cantonese, and in girls as compared to boys, but did not show significant improvement with age.

Research by Gudmundsdottir and Trehub (2017) on the ability of adults to identify melodies produced by toddlers challenges the view that early singing development focuses on words rather than melody and that vocal range is so limited. Many toddlers were able to negotiate large intervals and communicate the melodies to the adults (see also Costa-Giomi & Benetti, 2019).

Primacy of the singing voice Recent research has revealed that the singing voice is privileged among musical instrument sounds with regard to tolerance for error, a model for imitation, and memory. Hutchins, Roquet, and Peretz (2012) examined the ability to detect that a final note of a short musical passage was out of tune when the melody was either sung or performed on a violin. The decision to state that the note was out of tune required a significantly greater degree of difference for the vocal as compared to the instrumental condition. The authors referred to this as the *vocal generosity effect* (see also Warren & Curtis, 2015). In spite of this tolerance for vocal inaccuracy, adult participants who were asked to vocally imitate musical intervals performed best when the intervals were sung as compared to presented on a piano (Granot, Israel-Kolatt, Gilboa, & Kolatt, 2013). This result confirmed a previous finding of a similar positive influence of the singing voice on children's pitch accuracy (Green, 1990). A series of studies by Weiss and colleagues has revealed the privileged status of vocalized melody over melody played on an instrument with respect to memory in adults (e.g., Weiss, Trehub, & Schellenberg, 2012; Weiss Schellenberg, & Trehub, 2017) and children (Weiss, Schellenberg, Trehub, & Dawber, 2015). The impact of vocalized melodies over those performed on a musical instrument is also seen in pupil dilation (Weiss, Trehub, Schellenberg, & Habashi, 2016). These phenomena support the notion of the biological significance of vocal timbre.

Vocal Training

Stadler Elmer (2011) and Gudmundsdottir and Trehub (2018) suggest that support of a child's singing at home can account for early singing ability that exceeds the levels that might be expected from the proposed stages of the SVDM and the VPMD. A recent meta-analysis concludes that vocal accuracy of children benefits from vocal instruction (Svec, 2017). The nationwide "Sing Up" program in Britain revealed that children who received weekly singing classes over a three-year period showed trends in singing competency ahead of peers in classes that did not receive such an opportunity (Welch, Saunders, Papageorgi, & Himonides, 2012). Vocal training also benefits adult "nonsingers" (Numminen, Lonka, Rainio, & Ruismäki, 2015).

Siupsinskiene and Lycke (2011) obtained voice-range profiles from trained choir singers and nonsingers. Each group had over 150 participants, approximately one-half of whom were prepubescent children. When compared with persons who were not involved with singing, both genders of adults and child singers showed a higher mean pitch range, higher highest frequency, and greater VRP area in high frequencies. Females of both age groups showed additional effects associated with intensity. A set of parameters derived from the profiles led to a level of 80 percent correct in classifying a member as vocally trained or untrained. The change in the VRP as a result of training implies a gain in control of the voice with respect to pitch and loudness range and supports a view of lifespan plasticity of the vocal system.

Given the findings of Siupsinskiene and Lycke (2011), one might expect dramatic increases in frequency range with years of dedicated practice. Testing voice students over a period of three years of training, however, Pabon et al. (2014) found less change in the VRP than might be expected. Still, early obtained VRPs reflected disconnected voice registers (chest, middle, and head) and the later VRPs reflected a seamless continuity or sense of single register. The VRPs also showed that when the students entered the program they could sing more loudly for certain pitches than they could after three years of training. The students were unaware of their intensity loss. Thus, dedicated training has subtle effects on the voice, and what one might naively expect to see with classical training (wider range of pitch and loudness) is not necessarily the mark of the trained voice.

Hearing Impairment and Singing

While vocal production does not entirely rely on pitch acuity (Pfordresher et al., 2015), persons with a pronounced hearing impairment—profound deafness in the extreme case—are at a disadvantage when it comes to accurate singing. Nevertheless, such individuals may still enjoy singing as an avenue for artistic expression through music (Schraer-Joiner, 2014; Yennari, 2010) or joining in normal group activities. There is little research on the impact of hearing impairment on singing ability, although there is research on the use of singing to improve speech or music perception among persons with hearing impairment (e.g., Petersen, Morensen, Hansen, & Vuust, 2012). Trehub, Vongpaisal, and Nakata (2009) reported that shortly after receiving cochlear implants, toddlers preferred a video of a mother singing a playsong as compared to the same video in silence. They enjoyed singing spontaneously, but their productions failed to match a melody in either contour or pitch, in part due to use of a very limited vocal range, approximately one-third of that of a control group of children with normal hearing.[24] Timing of the first fifteen notes of a song was comparably good for the two groups. Research on singing with hearing aids and with cochlear implants may in the long run be able to assist hearing-aid manufacturers to improve hearing-aid or implant design so as to reduce distortion of music (and singing) by aids that naturally make speech representation the priority.

Changing Behavior through Singing

Language Learning

The "Every Child Ready to Read" research-based program of the American Library Association identifies singing as one of five practices of early literacy (i.e., singing, talking, reading writing, and playing), includes singing in community library programs for infants, toddlers, and preschoolers, and encourages parents to sing at home (Celano & Neuman, 2015; Neuman & Celano, 2012). Heydon and O'Neill (2016) and Heydon, Beynon, O'Neill, Zhang, and Crocker (2013) have promoted singing-infused intergenerational programs as a means of enhancing the multimodal literacy and wellbeing of both young children and older adults. Diverse studies have shown benefits to learning verbal material in one's native language when presented in a vocal music context (e.g., Calvert, & Tart, 1993; Schön et al., 2008; Wallace, 1994), although not all studies have shown that verbal learning benefits when words are sung as compared to spoken (e.g., Kilgour, Jakobson, & Cuddy, 2000; Racette & Peretz, 2007).

Evidence is also mounting for the facilitation of singing and song in second-language learning. Learning a foreign language entails learning foreign phrases that mean the same as phrases in one's native language. Ludke, Ferreira, and Overy (2014) reported the first experimental evidence that singing benefits learning of such paired associates. In their study, adults were randomly assigned to either a speaking, a rhythmic speaking, or a singing repetition learning condition. In tasks of both recall and production in the Hungarian language, the performance of those assigned to the singing condition exceeded that of the participants in the other two nonsinging conditions.[25] Good, Russo, and Sullivan (2015) also showed the benefits of singing lyrics versus learning prose in the acquisition of foreign language words for children in Colombia. A study that compared classes of students (first language English) and included either singing and song or visual art and drama revealed a significantly higher improvement from pre- to post-testing for the classes that were supplemented by singing and song (Ludke, 2016). Singing ability has also been related to acquisition of a native accent in a foreign language (Cornaz, Henrich, & Vallée, 2010; Flege, Munro, & MacKay, 1995). Singing is at a slower pace than speaking and provides more time to practice individual speech sounds. Vocal training focuses on audiomotor coordination (see figure 17.1) to match a target through appropriate muscle control. Singing may enable the image of an accurate target syllable and improve the control of the upper vocal tract and laryngeal muscles to match the target.

Promotion of Cultural Understanding

Learning and singing the songs of another culture may heighten identification with that culture as well as provide common ground with members of the other culture (Ilari, Chen-Hafteck, & Crawford, 2013; Monti, Aiello, & Carroll, 2016). In theory, learning the songs of a minority culture could reduce prejudice toward members of the minority culture. Félix Neto and colleagues in Portugal asked whether music (a singing program) could reduce anti-dark-skin prejudice. In a pre- post-intervention study, Sousa, Neto, and Mullet (2005) assessed anti-dark-skin prejudice in children who were between the ages of seven and ten years. Half of the sample received their usual music program of Portuguese songs, and the remaining half was exposed to African and Portuguese songs. The older children who received the bicultural singing program showed significantly reduced levels of prejudice, unlike the group who had learned only the Portuguese songs. In a follow-up study, reduction of anti-dark-skin prejudice endured after two years (the longest duration tested) (Neto, da Conceiçao Pinto, & Mullet, 2015). These impressive long-term results of a singing intervention contrast with the results of nine nonsinging interventions on reducing implicit racial preferences (Lai et al., 2016). All interventions were effective immediately but none endured after delay of as little as a few hours. Lai et al. (2016) point out that Neto et al.'s finding of positive long term attitude change "suggests that children's implicit preferences *can* remain changed for years after an intervention has taken place" (p. 1013). A similar successful singing intervention was obtained by Tu (2009) who organized ten-minute daily classroom exposure to a Chinese music curriculum over a ten-week period in grades three, four, and five in American schools.

In related work in a study of adults living in England, listening to approximately five minutes of Indian or West African popular music was associated with higher implicit affiliation scores for the respective culture in persons who exhibited high empathy, with both attitudes and trait empathy having been measured psychometrically (Vuoskoski, Clarke, & DeNora, 2017). While this study suggests that actual engagement in singing is not necessary to increase affiliative attitudes in persons with high empathy, it is unclear whether engagement in singing would have been sufficient to improve attitudes in persons with low trait empathy who had not been affected by simply listening. Moreover, the duration of the effects remains unclear. Chen-Hafteck et al. (2017) conducted an ambitious twelve-week study teaching the songs and culture of Brazil, Canada, China, and Kenya to children in two schools in each of the four countries. Control groups received only cultural instruction. Qualitative analyses of interviews suggested a broadening of cultural understanding in all cultures but Kenya (where favorable attitudes toward other cultures already existed) although results of a pre-post questionnaire showed no differences between the experimental (singing and culture) and control (culture only) classes, with the exception of children in one school in rural China. The study revealed the challenges of conducting cross-cultural work, where, for example, the ease of offering verbal opinion in an interview may be more natural in individualist as compared to collectivist cultures.

Group Cohesion in Choral Singing

The previous discussion has focused on studies that aim to improve the attitude of one group toward another through education about songs in a cultural context, without contact with the foreign group or groups. Other research, however, has focused on the benefits of engaging people in the same activity as a means of developing positive feelings and social bonds (Welch, Himonides, Saunders, Papageorgi, & Sarazin, 2014). Singing together allows synchronization in groups and involves physical exertion, both of which might encourage the release of endorphins and make people feel more socially close to one another. A series of original studies conducted in the United Kingdom provides evidence of these physiological effects, the fast bonding capacity of singing, known as the *ice-breaker effect* (Pearce, Launay, & Dunbar, 2015), and the capacity for singing to bond very large groups of people together at once (Weinstein, Launay, Pearce, Dunbar, & Stewart, 2016). Having a good social network has positive effects on health and wellbeing, so it can be argued that community choirs might provide an effective and economical means to improve health and reduce loneliness in the modern world. Good and Russo (2016) report a study in which children who engaged in singing showed greater cooperation in a prisoner's dilemma game than children engaged in other nonmusical activities. They suggest that the synchronized movement in singing is the key factor in enhancing empathy. Kirschner and Tomasello (2010) showed increased prosocial behavior in four-year-old children who sang and danced together.

Wellbeing

According to Chanda and Levitin (2013), music has four main effects on health: increasing experiences of reward and pleasure, buffering stress and arousal, strengthening immunity, and promoting social affiliation. There is evidence that the benefits of singing represent each of these categories. Nevertheless, singing can by no means be regarded as a panacea. For example, professional singers find their voice lessons less positive and more stressful than do amateur singers (Grape, Sandgren, Hansson, Ericson, & Thorell, 2002).

In a review of singing, health and wellbeing from a health psychologist's perspective took, Gick (2011) reported on evidence from over thirty-five studies that included singing as an intervention and that used quantitative or qualitative data. She concluded that "research on singing reviewed here often indicates anecdotal support and promising but inconclusive evidence" (Gick, 2011, p. 203). Rather than supporting the view that "singing for health may be an idea whose time has come" (as she quotes Stacy, Britain, & Kerr, 2002, p. 156), she suggests that "perhaps *research* in singing for health is an idea whose time has come (p. 203). The most recent article reviewed by Gick was from 2010, and since that time there has been further progress. This is not to say that research prior to that date has less merit, and the following section highlights examples of past and more recent work. First several studies that deal with choral singing are considered, then studies involving the benefits of engaging with singing individually are noted.

Benefits of choral singing Clift et al. (2010) reviewed forty-four studies showing the benefits of choral singing, including boosting the immune system (Beck, Cesario, Yousefi, & Enamato, 2000; Kreutz, Bongard, Rohrmann, Hodapp, & Grebe, 2004; see also Creech et al., 2013). More recent evidence suggests that engagement in regular choral singing can benefit the immune system of persons affected by cancer. Fancourt et al. (2016) studied nearly two hundred members across five different choirs and found that singing for just one hour boosts levels of immune proteins in people affected by cancer (caregivers, bereaved caregivers, and patients). The findings also showed reduced stress and improved mood, which in turn could have a positive impact on overall health. Participants with the lowest levels of mental wellbeing and highest levels of depression experienced greatest mood improvement, which is associated with lower levels of inflammation in the body. The findings raise the possibility that singing in choir rehearsals could help to put people in the best possible position to receive treatment and maintain remission. The stress, anxiety, and depression associated with cancer can suppress immune activity at a time when patients need as much support as they can get from their immune system. The research findings suggest that singing may relieve some of this stress-induced suppression, thereby helping to improve wellbeing and quality of life amongst patients.

Sanal and Gorsev (2014) reported decreased negative affect and state anxiety levels of members of a university choir after their one-hour rehearsal, compared to a control group. Kreutz (2014) showed increased positive affect, decreased negative affect, and increased oxycotin (associated with social bonding) after thirty minutes of rehearsal as compared to after thirty minutes chatting with a choir member. Choral groups of members sharing specific health issues or special circumstances have met with success on such common ground as homelessness (Bailey & Davidson, 2002), marginalization (Bailey & Davidson, 2005), incarceration (Cohen, 2009), social disadvantage (Dingle, Brander, Ballantyne, & Baker, 2012), learning disability (Hassan, 2017), refugee status (Balsnes, 2016), multiculturalism (Yerichuk, 2015), LGBTQI (Bird, 2017), Parkinson's disease (Tanner, Liu, & Rammage, 2015), lung disease (Tanner, Kalluri, & Richman-Eisenstat, 2016), aphasia (Tarrant et al., 2016), and dementia (e.g., Clements-Cortés, 2015; Särkämö et al., 2016).

Tonneijck, Kinébanian, and Josephsson (2008) conducted a qualitative study involving participant observation and interviews of middle-aged members of a small choir in Holland, which revealed three main themes underlying their choir experience: the challenge of choir singing, the value of engaging in a nonroutine activity, and the "the experience of enacting wholeness" (p. 178), facilitated by the safe environment. Bonshor (2016) interpreted the success of a seniors' choir in terms of a community of practice model, centered on a common interest in singing and shared learning and performance goals. Thus, social learning theory, with its focus on modeling and developing self-efficacy (Bandura, 1977), has application to the functioning of community choral groups. In a randomized control trial of persons with dementia, both group singing and listening to music in a group reduced symptoms of depression as compared to a control group but in different ways, with singing benefiting physical signs of depression (energy level and weight) and listening reducing behavioral disturbances such as agitation and loss of interest (Särkämö et al., 2016).

Engagement in group singing can also increase the pain threshold. Dunbar, Kaskatis, MacDonald, and Barra (2012) compared members of two religious groups, one of which engaged in singing. Endorphins are released during synchronized exertive movements and also during passive listening to music (Tarr, Launay, & Dunbar, 2014). Active singing was found to be more effective than music listening in elevating pain thresholds.

Benefits of individual singing

Alzheimer disease In addition to the value of group singing, singing directed to an individual may have benefit for specific ailments. It is well noted that singing is often spared in dementia (Cuddy et al., 2012. Brown, Götell, and Ekman (2001), and Götell, Brown, and Ekman (2002, 2003, 2009) studied the impact of caregiver singing on the emotions, moods, and communications in dementia care. The studies focused on the typical morning activities (dressing, washing, brushing of teeth) of persons with dementia and their caregivers. Three video-recorded sessions of each person with dementia included (1) regular activity, (2) background music, and (3) caregiver singing to or with the patient. Caregiving singing led to increased vocal clarity and expression, improved body posture and body awareness, and reduced aggressiveness towards caregivers (Götell et al., 2009, p. 429). While background music was also facilitative, caregiver singing had a unique impact on "vitality and mutuality," which is regarded as foundational to good nursing practice. The authors offer a basic psychological network theory of emotion as an explanation for the positive effects and argue for the inclusion of singing education as part of the professional training of caregivers and nursing students.

Stroke/Aphasia Persons who have difficulties speaking may successfully articulate words when singing. Speech communication disorders are often the consequence of stroke, which creates a lesion in the part of the brain responsible for speech. Two types of speech disorders, or *aphasia*, are distinguished, *fluent* and *nonfluent* (see chapter 14 by Gottfried Schlaug). Lesions involving Wernicke's area (posterior superior temporal lobe) are often associated with fluent aphasia. Recovery from aphasia may entail recruitment of homologous structures in the right hemisphere (Schlaug, Marchina, & Norton, 2008). Based on the clinical observation that persons with aphasia were able to sing words that they were unable to speak, Sparks and Holland (1976) developed a protocol called *Melodic Intonation Therapy* (MIT), which aimed to facilitate the restoration of speech by exploiting the connection to singing.

There are two components of MIT. The first entails engaging the patient in articulating words and simple phrases as a simple melody with an exaggerated up and down "melodic" contour. This component is intended to engage the right hemisphere, which is more sensitive to processing spectral information and slow temporal acoustic features (Schlaug, 2015; Schlaug, Norton, Marchina, Zipse, & Wan, 2010; Vines, 2011). The second aspect entails rhythmic tapping of the left hand (held by the therapist) in synchrony with each syllable (Thaut, Thaut, and McIntosh, 2015; Zumbansen, Peretz, & Hébert, 2014). Focusing on the details of the procedure itself to explain possible success of MIT, Altenmüller and Schlaug (2015) point to mechanisms based on reduction of speed, syllable lengthening, chunking (integration of different kinds of speech information and integration across hemispheres), and left-hand tapping of one syllable per second. Merrett, Peretz, and Wilson (2014) conclude that many mechanisms operating together may account for the effectiveness of MIT. These include the neuroplastic reorganization of language function, the activation of the mirror neuron system and multimodal integration, the use of shared or specific features of music and language, and motivation and mood. The multiplicity of mechanisms provide features of additivity, flexibility, and synergy, which may contribute to the effectiveness of MIT as compared to the application of one mechanism by itself. Stahl, Kotz, Henseler, Turner, & Geyser (2011), who provide a critical review of MIT, emphasize the benefits of the rhythmic aspect rather than singing itself. Gabrielle Giffords, the US senator whose language capacities were severely affected by a gunshot to her left hemisphere during an assassination attempt, benefited from intensive therapy that included a type of melodic intonation therapy (Giffords & Kelly, 2011).

Other disorders Parental singing can reduce the stay of at-risk hospitalized neonates while remaining in the relatively noisy neonatal intensive care unit (NICU), which is so different from a normal home environment (Shoemark, Hanson-Abromeit, & Stewart, 2015). Falk, Maslow, Thum, and Hoole (2016) have shown how singing training can increase control over verbal timing, which may help stuttering.

Future Research

Benefits of Singing versus Playing Musical Instruments

Much research in music psychology compares musicians and nonmusicians, but only a few of these studies have contrasted vocalists with performers on other instruments. Often the implicit definition of a musician is someone who plays a musical instrument. This view of a musician is also prominent in public discourse on the value of music in education or the value of music for life success. For example, an article entitled "Is Music the Key to Success?" which appeared in the *Sunday Review* of the *New York Times* (Lipman, 2013) explored the relation between serious music training and success in other fields by focusing on persons with outstanding attainments in their nonmusician careers. Those considered were all performers on musical instruments and included, for example, former Secretary of State Condoleezza Rice, a trained concert pianist; film-maker Woody Allen, who studied clarinet; broadcaster Paula Zahn, who studied cello; and Paul Allen co-founder of Microsoft and an amateur guitar player.[26] The implication is that playing a musical instrument will be beneficial. But what of engaging in singing or learning to master the instrument one carries within oneself? Can it be equally beneficial?

If indeed making music is beneficial, then for reasons of economy and educational and social policy, it is important to determine whether similar benefits of music engagement accrue for vocalists and instrumentalists. It seems obvious that training massive numbers of young people to sing is less costly than training them to play traditional band and orchestral instruments. The cost of musical instruments, their repair, storage, and transportation is one that schools can seldom afford for every child. Sharing instruments is a partial solution, but then private practice becomes a scheduling problem. For singing, the instrument is always available for practice. Providing teachers the means for supporting musical instrument training for every child in a school is more daunting than providing a choral director and voice teacher, though it must be remembered also that choral or voice teachers are highly skilled professionals who often undertake many years of training to optimize their talents with respect to artistry, leadership, and interpersonal skills and understanding.

Of the few studies comparing trained vocalists and instrumentalists, none, at the time of writing, has revealed generally superior cognitive benefit for the instrumentalists. Schellenberg (2004) investigated whether or not music training had an impact on IQ by randomly assigning 132 six-year-olds to one of four groups who received either weekly music keyboard lessons, voice lessons, drama lessons, or no extra-curricular lessons (control). The Wechsler Intelligence Scale for Children-Third Edition (WISC-III; Wechsler, 1991) was the primary outcome measure. After approximately a year, post-training IQ (WISC-III) scores were significantly higher for both music training groups as compared to the drama and control group. While the improvement was relatively modest although statistically significant, if such improvement continued with additional years of training the gain in IQ could be more substantial. Relevant to the present discussion is that there was no significant difference between the vocal and keyboard training groups.[27]

In a study with young adults, Bialystok and DePape (2009) examined the role of musical expertise and bilingualism on executive functioning in a spatial and auditory/verbal domain.

There were four groups of participants: highly trained musicians who played musical instruments, vocalists, unilingual nonmusicians, and bilingual nonmusicians. Musicians showed enhanced performance on both tasks as compared to a control group who lacked musical experience and were not bilingual. Performance of the singers and instrumentalists did not differ. On the auditory task, both musical groups outperformed those without music training regardless of whether they were bilingual, and they also outperformed those without music training on the spatial task (performing equivalently to those who were bilingual). Thus it was the extensive music training, not the particular motor training, that accounted for the superior performance of the musicians. Indeed, within the vocal group, those who also had extensive musical instrument experience performed no better than those vocalists who had no such extensive training on a musical instrument.

The equal superiority of vocalists and instrumentalists was shown for sensitivity to internal bodily sensations, technically known as *interoceptive accuracy*, in a study conducted by Kleber and colleagues (Schirmer-Mowka, Fard, Zamorano, Finkel, Birbaumer, & Kleber, 2015). Participants were asked to indicate whether an acoustic signal was synchronous or asynchronous with their own heartbeat. The task requires the integration of internal and external stimulation. Because of the acoustical aspect of the task, the authors predicted superior performance of musicians over nonmusicians. Because "singers use a more body-core centered and visceral nature of music production, involving organs and muscles of vital importance" (Schirmer-Mowka et al., 2015, p. 2), the authors speculated that singers would outperform the instrumentalists, who in the study were all string players. The singers and the string players performed significantly better on this difficult task than did the nonmusicians but not differently from each other.[28] Performance for vocalists was correlated with years of training, a correlation not observed for the string players. While this study provided the first demonstration of possible enhancement of interoceptive accuracy in musicians, it also once again shows that the musician's superior ability is independent of whether one has learned a musical instrument or one has studied singing. The authors suggest, however, that a difference in the sensitive period for learning a musical instrument as compared to learning to master the human voice might account for the correlation between age of onset of training and interoceptive accuracy in singers but not string players. The authors relate the superior interoceptive accuracy to increased activity of the right anterior insula. Comparisons of singers and nonsingers in an fMRI study highlighted the activity of the right anterior insula during singing with and without anesthetized vocal folds (Kleber, Zeitouni, Friberg, & Zatorre, 2013) and as a function of noise-masked auditory feedback (Kleber, Friberg, Zeitouni, & Zatorre, 2017).

Slater and Kraus (2016) compared young male adult vocalists, percussionists, and persons without music training on several perceptual and cognitive tasks. The musician groups outperformed the nonmusician group on tests of auditory working memory, sentence-in-noise, and of course musical competence. The percussionist and vocalist groups did not differ from each other. A further study, also of all male participants representing these same three categories of experience, had similar findings (Slater, Azem, Nicol, Swedenborg, & Kraus, 2017). However, vocalists showed better frequency discrimination and encoding of harmonics than percussionists, who in turn showed superior ability to encode rapid speech transients. This suggested that specific long-term musical training can strengthen related cognitive functions. Unexpectedly percussionists exceeded both vocalists and nonmusicians on a test of inhibitory control. This is the first evidence that training on a musical instrument (in this case percussion) as opposed to the voice (a melodic instrument) can positively impact a particular aspect of cognition, in this case inhibitory control.[29]

The proposal of different critical periods for highest impact of musical performance instruction might suggest the importance of providing training on a musical instrument early in life and training of the voice in teenage years. Yet, Svec's (2017) meta-analysis of thirty-four pre-post-intervention studies of the benefits of vocal instruction in the primary grades (ages five to eleven years) revealed that training improved singing for all ages, with the greatest effect being for eight years old. Because singing instruction for large numbers of students is less costly than musical instrument training, more research is needed from a very practical standpoint: every child deserves music training, and the question is how this can be delivered to all children most effectively and economically. Naturally providing training on both vocal and instrumental music is the ideal, but it is not the most practical solution. What is critical is providing children with the basics of music as a foundation for lifelong musical engagement in ways that are most relevant and practical for the particular child.

Toward a Dynamic Systems Model of Singing Acquisition

This chapter has reviewed research on singing from a music-psychological perspective. Coverage was broad because singing overlaps with many issues in music psychology and also raises issues that are unique because everyone carries the basic musical instrument inside. Singing engages a great deal of the brain, and it encompasses many skills, not just one. While every infant is typically sung to, and every child learns to sing naturally, development in adolescent and adult singing is subject to an enormous number of variables associated with the cultural and environmental influences including those of family, institutions (educational, religious, community organizations), media, and friends, as well as factors associated with the self, be it gender, personality, mental and physical ability, and the actual structures of the vocal apparatus itself.

Understanding the development of singing can benefit from a biopsychosocial context. Gick (2011) found such a perspective useful when grappling with the benefits of singing for health. However this approach can be taken in conjunction with others. An *interactionist approach* has been put forward by Gaunt and Hallam (2016) as a way of mapping "the complexity of interactions informing the individual's development of musical skills" (p. 464). The model identifies "macro, meso, and exo systems," all of which are the source of interactions with the individual, and the levels may potentially interact. Gaunt and Hallam (2016) illustrate the application of the model to an individual learning music skills across developmental periods. This is exactly the question at hand with respect to singing, which itself can entail many musical skills. The model is scaled at the level of interpersonal interactions and involves identifying various interactions that may have influence, direct or indirect. The fine grain of singing development is missed at this level of analysis. Yet the approach, which might be regarded as a dynamic systems-theoretic approach, can be applied at the smaller scale to account for changes in singing behaviors. For example, such a model might help to account for the situation of the adolescent male voice that necessitates a reorganization of the audio-motor map when commands that once produced a particular pitch need adjustment.

We may also view the development, maintenance, and decline of singing across the entire lifespan in terms of sensitive periods, or time points when certain environmental influences have more impact on brain activity (establishment of new synapses) than at other times. Thus, for example, there is evidence that only after the age of fourteen years did number of years of voice lessons increase the grey matter in the laryngeal control area (Kleber et al., 2016), potentially because of the priority given to speech before the age of fourteen. While the theory of sensitive periods is controversial, the example serves to show the need for a comprehensive theory of the development of singing. A dynamical systems approach provides a framework for understanding sudden large changes resulting from seemingly small effects while taking into account the biological, psychological, and social factors at play. A dynamical systems approach was effectively applied to early child development by Thelen and Smith (1998),[30] and recently an application has been extended to the analysis of video recordings of student-teacher interaction in violin and cello lessons (Küpers, van Dijk, & van Geert, 2014, 2017). In related work, Küpers, van Dijk, McPherson, and van Geert (2014) consider teacher-student interactions on micro- and macro-time scales and emphasize the need for adaptivity of the teacher to the student's increasing skill level and constant sense of self-efficacy. The extension of such studies to the voice studio would seem fruitful especially since video-recording equipment is becoming more common technology in the voice studio (Gerhard & Rosow, 2016). The availability of new technologies for capturing, analyzing, and storing audio, audiovisual, and physiological information associated with singing can provide much needed data to enable theoretical advances.

Concluding Comment

In summary, singing entails many skills. It goes beyond singing accuracy, which has attracted much researcher attention, and should continue to do so, because it is important to know the extent to which the average person can sing in tune, the influence of vocal training on improving accuracy, and the impact of hearing handicap on singing in tune. But there are many other singing skills, such as, for example, remembering how to sing entire musical pieces, integrating words and melody, improvising songs, and singing in harmony. While singing is more closely connected to the arts than is speaking, singing also can serve nonmusical goals such as aspects of language acquisition. It has social implications—establishing a sense of trust in infants, reduction of a sense of isolation and the promotion of group cohesion through choral singing, the promotion of cultural understanding through learning songs of other cultures, and the enhancement of empathy when singing together. Singing indirectly enriches lives by bringing people together. Singing benefits healthy individuals as well as those with various health conditions such as Parkinson's disease, lung disease, stroke, and cancer.

A pressing question remains regarding the relative benefits of engaging in singing versus engaging in performance of a musical instrument. The answer to that question will have both theoretical interest and practical implications—as teaching music through singing can reach more children with tax payer dollars than can teaching music through band or orchestra, though of course ideally it is better to have both opportunities.

Increasing globalization has increased the need for a comprehensive general model of singing development and engagement that considers idiosyncratic, cultural, vocal and music training, and universal factors common to all. Such a model will enable predictions not only about the positive consequences of singing activities but also the effect of certain variables on singing behaviors. A dynamic systems approach coupled with a biopsychological framework may well accommodate the complexity of this challenge for music psychology. In view of the fact that singing is fundamental to so many aspects of music behaviors, including its very origins, a comprehensive model of singing will also further the foundation of much of the field of music perception and cognition

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Notes

1. A distinction is made between human and nonhuman singing, because in fact considerable interest has been directed to birdsong for several decades. Parallels with human speech rather than singing typically motivated this line of research, and continue to do so. Studies of human singing have been growing at a faster pace than that of birdsong and psychology as a whole in recent years.

2. For over fifty years, Sundberg has dedicated his career to the study of vocal production and perception. This came about when conducting graduate studies on the acoustics of the pipe organ at the University of Uppsala in Sweden. Needing more information about acoustics, he turned to the laboratory of Gunnar Fant in Stockholm, a key pioneer of speech production and analysis. Intrigued by Sundberg's inquiries, Fant enabled Sundberg to establish a musical acoustics laboratory in his own speech laboratory (see Cohen, 2011a).

3. The lowest note for the professional contrabass has been given as $Bb_1 = 58.3$ Hz.

4. Praat is freely downloadable. YIN (de Cheveigné & Kawahara, 2002) is a Matlab alternative. Computerized Speech Laboratory is a commercially available instrument offering pitch analysis, developed by Kay Elemetrics and marketed by PENTAX.

5. Electrolaryngography (Lx) and electroglottography (EGG) are noninvasive methods for measuring human vocal fold vibration in speaking and singing (as reviewed by D'Amario &Daffern, 2017). The EGG technique entails placing electrodes on either side of the neck to monitor the opening and closing of the vocal folds. The Lx technique adds a second vertical level of electrodes to track vertical movements of the larynx.

6. Sundberg (2003, 2013) prefers the term *singer's formant cluster*, as more than one formant frequency band is involved.

7. Even in the case of an instrument such as the piano, the optimal manner of touching the piano keys and moving from one key to another can require years of practice.

8. Conveying emotional information in singing entails control of at least six parameters identified recently by Scherer, Sundberg, Fantini, Trznadel, and Eyben (2017) (loudness, perturbation variation, low frequency, formant amplitude, and f_o) in an analysis of professional opera singers who were asked to convey specific emotions while singing up and down a musical scale.

9. Recall that Riecker, Ackermann, Wildgruber, Dogil, and Grodd (2000) suggested the anterior insula coordinates vocal tract movement in singing.

10. DES is an exploratory technique used since the early days of neurosurgery to avoid destruction of speech centers during brain surgery for intractable seizures or otherwise unmanageable critical medical conditions. After a portion of the skull is temporarily removed, ultrasound first determines the location of the lesion.

11. Accompanying the publication is a link to a video of the actual procedure showing the electrode placement and the patient's verbal response of four syllables. On three occasions, the patient sings. There was apparently additional evidence not provided in the video.

12. The pars opercularis is part of Brodmann area 44 (B44) on the left side, known as *Broca's area*. Brown, Martinez, and Parsons (2006) have also noted greater activation in the right than left pars opercularis for generation of melodies versus sentences, respectively, when testing only persons without specialized musical training. The right pars opercularis has been associated with response inhibition and inhibition of speech. A parallel is drawn between the spontaneous activation/suppression of the singing and speech systems and similar evidence of activation/suppression of two languages in bilingual persons.

13. While the exact borders of Wernicke's area are a matter of debate, the left sided posterior superior temporal gyrus is commonly assumed to be a part of it. The area uncovered with electrical stimulation (and thereafter cooled) was within the parallel location on the right side (Kalman Katlowitz & Michael Long, personal communication, 2017).

14. Focal cooling caused the fundamental (pitch) of vowels for speech to increase by a small audible amount. For both singing and speech, the first and second formants increased slightly in frequency. When the cortex returned to its original state of warmth, these formant changes returned to baseline. Because the vocal tract shape creates the resonances that influence the formant frequencies, it would appear that the stimulated area of the brain slightly influenced the muscles of the vocal tract.

15. The location coincided with the area identified by Penfield and Rasmussen (1950), though excluded in the canonical homunculus typically found in introductory psychology text books.

16. Note that the anterior cingulate cortex and anterior insula are key components of the Salience Network (Sridharan, Levitin, & Menon, 2008) shown by Alluri et al. (2017) and others to differentiate musicians and nonmusicians.

17. The identification of play and soothing songs was identified by the situational context, which the experimenter recorded at each session in the home of the parent. For example, a soothing context was designated when the song was sung when the infant was comforted when distressed or was being put to bed.

18. While true for the musics and languages of Western cultures, exceptions are found in other cultures of the world (List, 1963).

19. The view is that the default mode of singing is an emotional one, following the neuropsychological modular theory of Peretz and Coltheart (2003).

20. The AIRS (Advancing Interdisciplinary Studies in Singing) project addressed several large research questions: How does singing develop in every person, how should singing be taught and used to teach, and how does singing impact upon wellbeing? That ATBSS focuses primarily on the first question. Such information, however, would also provide a foundation for questions about the teaching and learning of singing and didactic uses of singing. Finally, understanding how singing developed would also set parameters for the application of singing to improving the human condition—finding that all people can sing and can improve their singing at any age could do much to open possibilities for the benefits of singing for society (Cohen, 2011b).

21. In a case study, one gentleman was tested with the ATBSS on seven occasions over the course of approximately three years between the ages of eighty-four and eighty-seven, during which time he took approximately fifteen voice lessons over the course of each year, with breaks for summer holidays, and periods of extended travel, occasional travel, and routine illnesses. Part of his motivation was to retain a youthful voice, as he was aware of voice changes with age. He himself had been a clinical psychologist in private practice until recent years. His sensitivity to key change as measured in the repeated singing of a familiar folk song more closely resembled that of highly trained musicians and over the course of the three years showed no evidence of decline in this regard (Cohen & Pan, 2015).

22. The typicality of this negative experience finds expression as the theme of the Hungarian film entitled *Sing* (Deák & Udvardy, 2016), which received the 2017 Academy Award for Best Live Action Short Film.

23. Criteria for each stage for both tests are reprinted in Welch (2016, p. 456). Welch (1986) lists five rather than four stages.

24. The limited vocal range might arise from poor control of fundamental frequency (Osberger & McGarr, 1982).

25. The target language was Hungarian, chosen because of little prior exposure to this language as compared to French, German, or Spanish, for example.

26. Lipman has a special relation to musical instrument training (as documented in Lipman & Kupchinsky, 2013) as an accomplished violist. She herself is a success as editor-in-chief of *USA Today* and *USA Today Network*, and Chief Content Officer of the Gannett publishing company.

27. It is interesting to note the equal benefit of vocal and keyboard training in spite of the fact that Kleber et al. (2016), as described earlier, suggest that the impact of voice training on increased gray-matter in right S1 and the supramarginal gyrus really begins after the linguistic-motor system has been established (around the age of fourteen years).

28. Yet the singers had approximately half as many years of training, practiced one-third less hours per week (12.4 vs. 19.8 hours), and commenced training much later (17.3 years vs. 6.8 years for string players).

29. The studies reviewed above, which compared effects of singing experience versus experience playing a musical instrument, were all conducted on participants in the younger part of the lifespan. However, large-scale survey conducted in Holland obtained measures of cognitive function in 1,101 persons over the age of sixty-three years (Mansens, Deeg, & Comijs, 2017). The findings indicated that those who sang and/or played a musical instrument had better attention, executive functioning, and episodic memory than those who did not make music; however, those who played musical instruments had higher processing speed scores than those who sang. The authors suggest that the result might be related to genre of music or extent of prior music training, which were not measured.

30. Thelen in fact had collaborated on a paper in which her theory was applied to learning cello, and the transfer of those ideas to singing could be straightforward (Winold & Thelen, 1994).

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