The Impact of the Auditory System on Phonation: A Review

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Summary: Objectives. The relationship between the auditory system and voice production has been studied extensively in those with impaired hearing, indicating the potential importance of the auditory system to the voice. However, there has been only limited study on the phonatory implications in those with superior auditory systems. This article examines the current literature on the effects of different auditory system characteristics on voice quality and accuracy.

Methods. The following databases were searched from their inception to November 2013: PubMed, EBSCO, and CINAHL. The following keywords were used: "hearing impaired," "auditory system," "voice," "professional voice user," "hearing," "singing," and "hearing loss." The references of articles were studied to identify further relevant citations. Additionally, Internet searches of Google and Google Scholar were performed. Relevant articles in English were included for review. Studies were excluded on article selection criteria, search strategy followed, search keywords, and searched databases.

Results/Conclusions. Current literature on the relationship between the auditory system and voice production focuses mostly on the hearing impaired, in which the changes in voice involve alterations in respiration, phonation, and articulation. Evidence on the phonatory effects of a superior auditory system is more limited. There is conflicting evidence as to the existence of a relationship between auditory pitch discrimination and vocal pitch accuracy. The role of the internal model on this relationship and the effects of training on enhancing and modifying the neural areas involved in the model have been studied. Professional singers have also been studied, examining the effects of training on auditory feedback and pitch accuracy. These studies have also produced inconsistent results. Further research is needed.

Key Words: Auditory system–Voice–Hearing impaired–Professional singing.

INTRODUCTION

The auditory system is believed to be a key component in the development and maintenance of excellent voice quality and accuracy. Individuals with profound hearing impairment or total deafness may have impaired voice quality, in addition to common abnormalities in resonance and speech. The possibility of the reverse scenario, a superb auditory system providing better-than-average voice quality, has not been studied well, and the effects of various levels of auditory performance on voice remain largely unknown. This review examines the literature on the effects of different auditory system characteristics on voice quality and accuracy. We believe that it is important to be familiar with what is known currently on this topic and to consider directions for future research.

METHODS

The following databases were searched from their inception to November 2013: PubMed, EBSCO, and CINAHL. The following keywords were used: "hearing impaired," "auditory system," "voice," "professional voice user," "hearing," "singing," and "hearing loss." The references of articles were studied to identify further relevant citations. Additionally, Internet searches of Google and Google Scholar were performed.

Relevant articles in English were included for review. Studies were excluded on the basis of the search strategy followed, search keywords, search databases, and articles listed in the search that did not address the topic of interest.

BACKGROUND

The production of speech is still not understood fully, but it begins in the brain with a premotor process involving the integration of several kinds of information: auditory, somatosensory, and motor. This information is found in the temporal, parietal, and frontal lobes, including the areas of the brain specialized for speech such as Broca's and Wernicke's areas and elsewhere.[1] The premotor process consists of three general tasks: production of an idea, word finding, and then syllabification or production of sounds needed to make each of the words. After this process is complete, articulation is created through three key neural pathways: the cerebellar motor path, pyramidal, and extrapyramidal tracts. These tracts synapse in the medulla, which controls the muscles involved in speech such as those of the tongue, lips, and larynx.[2] The complex activities involving the larynx and vocal tract that result in phonation are well known.[3]

The auditory system provides two types of control over speech production: feedback control and feedforward control. Feedback control allows for corrections in phonation using the sensory information acquired while the task is in progress. Feedback allows for a speaker or singer to increase volume in a noisy environment or modulate pitch to match a target.[4] Feedforward control allows for speech or song to be produced based on previously learned commands without needing constant auditory feedback. Feedback is vital in developing and maintaining normal vocal production.[5] The auditory feedback system is thought to have three roles: (1) providing information

Accepted for publication March 24, 2014.

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Journal of Voice, Vol. 28, No. 6, pp. 688-693
0892-1997/$36.00

http://dx.doi.org/10.1016/j.jvoice.2014.03.018

regarding vocal targets, (2) providing feedback about environmental conditions that may affect the quality of vocal production, and (3) contributing to the generation of internal models for the motor plans for voice production.[5] The first role of feedback is important for corrections in pitch, volume, and other attributes that may affect intelligibility of speech. The second role is important in noisy situations, for example, so that the speaker knows to enunciate more clearly, increase amplitude, and reduce speaking rate to increase intelligibility.[5] The third role is essential to the maintenance of a rapid speech rate through development of internal models, allowing for the vocal tract and related structures to be prepared before vocalization and for speech to continue without constant auditory feedback.[6,7]

Feedforward control uses internal models to control speech speed and voice without dependence on real-time auditory feedback. Given the rapid rate of normal speech, it would be impossible for feedback to be processed and corrections set in place before each new segment of speech if the same rapid rate were to be maintained. Feedforward control solves this problem.[6] Feedforward control also allows for speech fluency in postlingually deafened individuals and for phonation in loud noise.[4] It is used by singers performing with orchestras or choirs that mask auditory feedback, for example.

DISCUSSION

Hearing impaired

Hearing impairment provides an obvious, if extreme, example of the importance of audition to phonation and speech. The changes found in the voices of severely hearing impaired people involve alterations in respiration, phonation, and articulation.[8]

Respiration

The lungs provide airflow to allow for vocal fold oscillation. The chest, back, and abdominal musculature contribute to the production of this airflow. The respiratory system also plays a role in controlling pitch through modulating expiratory pressures which can increase or decrease pitch.[9]

Das et al[10] demonstrated that despite the presence of normal and healthy lung function, children with profound bilateral sensorineural hearing loss (SNHL) have a significantly lower vital capacity and maximum sustained phonation in comparison with normal hearing children. The reduction in vital capacity translates to these children having lower lung volumes to use for vocal production. Lower lung volumes force these children to take more pauses during speech; hence, they are unable to produce the normal amount of syllables per breath or to sustain a song line for as long as normal. The reduction in maximum sustained phonation is a measure of the individual's ability to manage air supply effectively during voice production. These combined respiration issues lead to changes in pausing patterns during speech with the overall effect leading to a decrease in speech intelligibility.[10] It may be speculated that this relatively suboptimal performance in the power source of the voice also predisposes to phonatory inefficiency and possibly vocal injury, but studies of this possibility are needed.

Phonation

Much of the literature on the hearing impaired and voice production focuses on phonation. Das et al[10] found uncoordinated contraction and relaxation of the intrinsic and extrinsic laryngeal muscles in the hearing impaired. They discovered a significant reduction in the fast adduction/abduction rate in children with profound bilateral SNHL compared with normal hearing children. From these results, the authors concluded that individuals with SNHL have difficulty in controlling subglottal pressure and tension of the vocal folds, and these difficulties affect phonation.

Ubrig et al[8] studied fundamental frequency and its' variability in 40 postlingually deaf adults before and after cochlear implantation (CI). Despite the fact that these individuals have internal motor models and patterns based on their prior hearing experience, there was still a significant difference in phonation without feedback control of the auditory system. The authors noted a significant reduction in fundamental frequency (in males) and a significant reduction in variation in frequency during sustained vowel production (in both genders) after CI compared with their performance before CI. However, once these findings were compared with the control group without CI in both time periods, only the variability in males remained statistically significant. The reductions in variation with sustained vowel production after CI demonstrate that, with auditory feedback, individuals can control their voices better with fewer variations in frequency.

Xu et al studied 21 children, seven perlingually deafened children with cochlear implants and 14 children with normal hearing and their ability to sing accurately. Each child sang one song, and the fundamental frequencies of each note were analyzed. Although there was no difference between the two groups in terms of rhythm, the children with CI had a significantly poorer performance in terms of pitch accuracy. Children with CI had a mean deviation of the pitch intervals of 2.86 semitones in comparison with those with normal hearing with a mean deviation of only 1.51 semitones. Despite this deficit in pitch, the authors comment on the achievement of singing in the CI children, given the obstacles of imperfect pitch information supplied by the CI. The authors speculated that deficits in singing skills are a result of poor pitch discrimination skills in the children with CI.[11]

Articulation

The unique shape of each individual's vocal tract creates vocal individuality and affects audibility. Changes can be made to the voice by altering the position of the tongue and soft palate and the shape of the pharynx.[3] It is accepted generally that such adjustments are made based on auditory feedback and that excellent auditory and vocal abilities are present in elite professional voice users. However, there are no convincing data to confirm or refute this belief, although some findings in hearing impaired patients suggest that the link between audition and phonation can be confirmed at least in that population.

For example, Das et al[10] discovered that children with profound bilateral SNHL have more nasal speech than those with normal hearing. The hypernasality is caused by incomplete