

The accompanying figures indicate the number of vibrations per second in the corresponding tone. It is evident that from  $c'$  to  $f'$  is common to all voices; nevertheless, they have a different timbre. The lowest note or tone, which, however, is only occasionally sung by bass singers, is the contra-F, with 42 vibrations; the highest note of the soprano voice is  $a''$ , with 1,708 vibrations (Landois and Stirling).

There is really no great difference in the mechanism of the different kinds of voice, and the differences in pitch are due chiefly to the greater length of the vocal chords in the low-pitched voices and to their shortness in the higher voices. The differences in quality are due to peculiarities in the conformation of the larynx, to differences in its size and to variations in the size and form of the auxiliary resonant cavities. Great changes in the quality of the voice may be effected by practice. A cultivated note, for example, has an entirely different sound from a harsh, irregular vibration; and by practice, a tenor may imitate the quality of the bass, and *vice versa*, although the effort is unnatural. It is not at all unusual to hear male singers imitate very closely the notes of the female, and the contralto will sometimes imitate the voice of the tenor in a surprisingly natural manner.

*Action of the Intrinsic Muscles of the Larynx in Phonation.*—In the production of low chest-notes, in which the vocal chords are elongated and are at the minimum of tension that will allow of regular vibrations, the crico-thyroid muscles are undoubtedly brought into action, and these are assisted by the arytenoid and the lateral crico-arytenoids, which combine to fix the posterior attachments of the vibrating ligaments. It will be remembered that the crico-thyroids, by approximating the cricoid and thyroid cartilages in front, increase the distance between the arytenoid cartilages and the anterior attachment of the vocal chords.

As the notes produced by the larynx become higher in pitch, the posterior attachments of the chords are approximated, and at this time the lateral crico-arytenoids are probably brought into vigorous action.

The uses of the thyro-arytenoids are more complex; and it is probably in great part by the action of these muscles that the varied and delicate modifications in the rigidity of the vocal chords are produced.

The differences in singers as regards the purity of their notes are due in part to the accuracy with which some put the vocal chords upon the stretch; while in those in whom the voice is of inferior quality, the action of the muscles is more or less vacillating and the tension is frequently incorrect.

The fact that some singers can make the voice heard above the combined sounds from a large chorus and orchestra is not due entirely to the intensity of the sound, but in a great measure to the mathematical equality of the sonorous vibrations and the comparative absence of discordant waves.

*Action of Accessory Vocal Organs.*—A correct use of the accessory organs of the voice is of great importance in singing; but the action of these parts is simple and does not require a very extended description. The human vocal organs, indeed, consist of a vibrating instrument, the larynx, and of certain tubes and cavities by which the sound is re-enforced and modified.

The trachea serves, not only to conduct air to the larynx, but to re-enforce the sound to a certain extent by the vibrations of the column of air in its interior. When a powerful vocal effort is made, it is easy to feel, with the finger upon the trachea, that the contained air is thrown into vibration.

The capacity of the cavity of the larynx is capable of certain variations. In fact, both the vertical and the bilateral diameters are diminished in high notes and are increased in low notes. The vertical diameter may be modified slightly by ascent and descent of the true vocal chords, and the lateral diameter may be reduced by the action of the inferior constrictors of the pharynx upon the sides of the thyroid cartilage.

The epiglottis, the superior vocal chords and the ventricles are by no means indispensable to the production of vocal sounds. In the emission of high notes the epiglottis is somewhat depressed, and the superior chords are brought nearer together; but this affects the form of the resonant cavity only above the glottis. In low notes the superior chords are separated. It was before the use of the laryngoscope in the study of vocal phenomena that the epiglottis and the ventricles were thought to be so important in phonation. Undoubtedly, the epiglottis has something to do with the character of the voice; but its action is not absolutely necessary or even very important, as has been shown in experiments of excising the part in living animals.

The most important modifications of the laryngeal sounds are produced by the resonance of air in the pharynx, mouth and nasal fossæ. This resonance is indispensable to the production of the natural, human voice. Under ordinary conditions, in the production of low notes the velum palati is fixed by the action of its muscular fibres, so that there is a reverberation of the bucco-pharyngeal and naso-pharyngeal cavities; that is, the velum is in such a position that neither the opening into the nose nor the opening into the mouth is closed, and all of the cavities resound. As the notes are raised in pitch, the isthmus contracts, the part immediately above the glottis is also constricted, the resonant cavity of the pharynx and mouth is reduced in size, until finally, in the highest notes of the chest-register, the communication between the pharynx and the nasal fossæ is closed, and the sound is re-enforced entirely by the pharynx and mouth. At the same time the tongue—a very important organ to singers, particularly in the production of high notes—is drawn backward. The point being curved downward, its base projects upward posteriorly and assists in diminishing the capacity of the bucco-pharyngeal cavity. In the changes which the pharynx thus under-



goes in the production of different notes, the uvula acts with the velum and assists in the closure of the different openings. In singing up the scale, this is the mechanism, as far as the chest-notes extend. When, however, a singer changes into what is sometimes called the head-voice (falsetto), the velum palati is drawn forward instead of backward, and the resonance takes place chiefly in the naso-pharyngeal cavity.

*Laryngeal Mechanism of the Vocal Registers.*—One difficulty at the very beginning of a discussion of this subject is in fixing upon clear definitions of what are to be recognized as different vocal registers. In the first place it must be understood that the singing voice is very different from the speaking voice. Without being actually so far discordant as to offend a musical ear, the ordinary voice in speaking never has what may strictly be called a musical quality, while the perfect singing voice produces true musical notes. This is probably due to the fact that the inflections of the voice in speaking are not in the form of distinct musical intervals, that the vibrations follow each other and are superimposed in an irregular manner, and that no special effort is made to put the vocal chords upon any definite tension, unless to meet a more powerful expiratory effort when the voice is increased in force. A shout or a scream is entirely different from a powerful, singing note. This difference is at once apparent in contrasting recitative with ordinary dialogue in operatic performances.

The divisions of the voice into registers, made by physiologists, are sometimes based upon theories with regard to the manner of their production; and if these theories be not correct, the division into registers must be equally faulty. Again, there are such marked differences between male and female voices, that it does not seem possible to apply the same divisions to both sexes. There is no difficulty, however, in recognizing the qualities of voice, called bass, barytone and tenor, in the male, or contralto, mezzo and soprano, in the female. A division of the voice into registers should be one easily recognizable by singers and singing teachers; and this must be different for male and female voices. If a division were made such as would be universally recognized by the ear, irrespective of theories, it would remain only to ascertain as nearly as possible the exact vocal mechanism of each register. It must be remembered that the voice of a perfect singer shows no recognizable break, or line of division between the vocal registers, except when a difference is made apparent in order to produce certain legitimate musical effects. One great end sought to be attained in training the voice in singing is to make the voice as nearly as possible uniform throughout the extent of its range; and this has been measurably accomplished in certain singers.

Judging of different registers entirely by the effect produced upon the ear, both by cultivated and uncultivated singers, the following seem to be the natural divisions of the male voice:

1. The chest-register. This is the register commonly used in speaking. Though usually called the chest-voice, it has, of course, no connection with any special action of the chest, except, perhaps, with reverberation of air in

the trachea and the larger bronchial tubes. This register is sensibly the same in the male and in the female.

2. The head-register. In cultivated male voices, a quality is often produced, probably by diminished power of the voice, with some modification in the form and capacity of the resonant cavities, which is recognized as a "head-voice," by those who do not regard the head-register as equivalent to the falsetto.

3. The falsetto-register. By the use of this register, the male may imitate the voice of the female. Its quality is different from that of the chest-voice, and the transition from the chest to falsetto usually is abrupt and quite marked. It may be called an unnatural voice in the male; still, by very careful cultivation, the transition may be made almost imperceptibly. The falsetto never has the power and resonance of the full chest-voice. It resembles the head-voice, but every good singer can recognize the fact that he employs a different mechanism in its production.

Applying an analogous method of analysis to the female voice, the natural registers seems to be the following:

1. The chest-register. This register is the same in the female as in the male.

2. The lower medium register, generally called the medium. This is the register commonly used by the female in speaking.

3. The upper medium register. This is sometimes called the head-register and is thought by some to be produced by precisely the same mechanism as the falsetto-register in the male. It has, however, a vibrant quality, is full and powerful, and is not an unnatural voice like the male falsetto.

4. The true head-register. This is the pure tone, without vibrant quality, which seems analogous to the male falsetto.

*Vocal Registers in the Male.*—According to the division and definitions just given of the vocal registers, in the male voice there is but one register, extending from the lowest note of the bass to the falsetto, and this is the chest-register. In the low notes, the vocal chords vibrate, and the arytenoid cartilages participate in this vibration to a greater or less extent. In the low notes, also, the larynx is open; that is, the arytenoid cartilages do not touch each other. As the notes are raised in pitch, the arytenoid cartilages are approximated more and more closely, and they touch each other in the highest notes, the vocal chords vibrating alone. It is probable that the degree of approximation of the arytenoid cartilages is different in different singers, and that the part of the musical scale at which they actually touch is not invariable. This appears to be the case in the observations made by Mills.

What has been called, in this classification, the head-register of the male, is not a full, round voice, but the notes are more or less *sotto voce*. This peculiar quality of voice does not seem to have been made the subject of

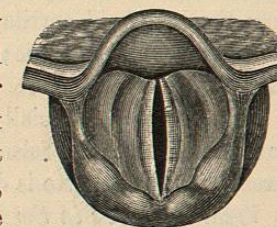


FIG. 170.—Appearance of the vocal chords in the production of the chest-voice, after Mandl (Grützner.)



laryngoscopic investigation. It has a vibrant character, which is undoubtedly modified by peculiar action of the resonant cavities, which latter has not been described. It is not probable that its mechanism differs essentially, as regards the action of the glottis, from that of the full chest-register, shown in Fig. 170.

The falsetto-register in the male undoubtedly involves such a division of the length of the vocal chords that only a portion is thrown into vibration. There is always an approximation of the chords in their posterior portion, and sometimes also in their anterior portion. This is illustrated in Fig. 171.

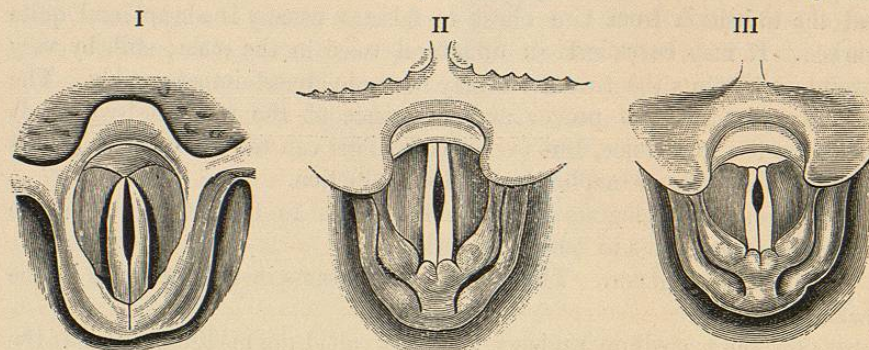


FIG. 171.—Appearances of the vocal chords in the production of the falsetto-voice (Mills).  
I. The larynx during falsetto-production; after Mandl.  
II. The larynx during the emission of falsetto-tones; middle range; after Holmes.  
III. The larynx of the female during the production of head-tones, as seen by the author (Mills).

The mechanism by which the vocal chords are approximated in portions of their length has not been satisfactorily explained; but laryngoscopic examinations leave no doubt of the fact of such action. The extent of this shortening of the chords must vary in different persons and in the same person, probably, in the production of falsetto-notes of different pitch. According to Mrs. Seiler, the shortening is due to the action of a muscular bundle, called the internal thyro-arytenoid, upon little cartilages extending forward from the arytenoid cartilage, in the substance of the vocal chords, as far as the middle of the glottis; but dissections made by Mills failed to confirm this view.

Some singers, especially tenors, have been able by long practice to pass from the chest to the falsetto so skillfully that the transition is scarcely apparent, but the falsetto is devoid of what is called vibrant quality.

*Vocal Registers in the Female.*—There is absolutely no difference between the vocal mechanism of the chest-voice in the sexes. In the best methods of teaching singing, one important object is to smooth the transition from the chest-voice to the lower medium. The full chest-notes, especially in contraltos, closely resemble the corresponding notes of the tenor.

According to the laryngoscopic observations of Mills, the mechanism of the lower medium and upper medium in females does not radically differ from the mechanism of the chest-voice. In these registers, the arytenoid cartilages become more and more closely approximated to each other as the voice ascends in the scale until, in the higher notes, they probably are firmly

in apposition. It is probable that the vocal chords alone vibrate in the lower and upper medium, while the apophyses of the arytenoid cartilages participate in the vibrations in the female chest-voice.

The vocal chords are much shorter in the female than in the male. According to Sappey, the average length in the male is about  $\frac{3}{4}$  of an inch (22 mm.) and in the female, about  $\frac{2}{3}$  of an inch (17 mm.). If the chords alone vibrate, without the apophyses of the arytenoid cartilages, the difference in length would account for the differences in pitch of the voice in the sexes. The tenor can not sing above the chest-range of the female voice without passing into the falsetto, to produce which he must actually shorten his vocal chords so that they are as short or shorter than the vocal chords of the female. This is shown by the scale of range of the different voices compared with the length of the vocal chords; and this idea is sustained still farther by a comparison of "the larynx during falsetto production" (Fig. 171, I). In the male falsetto, produced by this shortening of the vocal chords, the more nearly the resonant cavities are made to resemble, in form and capacity, the corresponding cavities in the female, the more closely will the quality of the female voice be imitated. It is probable that the vocal bands in the female present a thinner and narrower vibrating edge than the chords in the male, although there are no exact anatomical observations on this point. This would account for the clear quality of the upper registers of the female voice as compared with the male voice or with the female chest-register. Analogous differences exist in reed-instruments, such as the clarinet and the bassoon. This comparison of the female upper registers with the male falsetto does not necessarily imply a similarity in the mechanism of their production, as is assumed by some writers. The vocal chords, in the female lower and upper medium, vibrate in their entire length; in the male falsetto, the chords are artificially shortened so that they are approximated in length to the length of the chords in the female.

To reduce to brief statements the views just expressed, based partly upon laryngoscopic examinations—that are far from complete—by a number of competent observers, the following may be given as the mechanism of the vocal registers in the female, taking no account of the changes in form and capacity of the resonant cavities:

1. The chest-voice is produced by "large and loose vibrations" (Garcia) of the entire length of the vocal chords, in which the apophyses of the arytenoid cartilages participate to a greater or less extent, these cartilages not being in close apposition.
2. In passing to the lower medium, the arytenoid cartilages probably are not closely approximated, but they do not vibrate, the vocal chords alone acting.
3. In passing to the upper medium, the arytenoid cartilages probably are closely approximated, and the vocal chords alone vibrate, but they vibrate in their entire length.
4. The head-register, which may be called the female falsetto, bears the same relation to the lower registers in both sexes. The notes are clear but



deficient in vibrant quality. They are higher in the female than in the male because the vocal chords are shorter. Laryngoscopic observations demonstrating this fact in the female are as accurate and definite as in the male. (See Fig. 171.)

The reasons why the range of the different vocal registers is limited are the following: Within the limits of each register, the tension of the vocal chords has an exact relation to the pitch of the sound produced. This tension is of course restricted by the limits of power of the muscles acting upon the vocal chords, for high notes, and by the limit of possible regular vibration of chords of a certain length, for low notes. The higher the tension and the greater the rigidity of the chords, the greater is the force of air required to throw them into vibration; and this, also, has, of course, certain limits. It is never desirable to push any of the lower registers in female voices to their highest limits. All competent singing teachers recognize this fact. The female chest-register may be made to meet the upper medium, particularly in contraltos; but the singer then has practically two voices, a condition which is musically intolerable. In blending the different registers so as to make a perfectly uniform, single voice, the arytenoid vibrations should be rendered progressively and evenly less and less prominent, until they imperceptibly cease when the lower medium is fully reached; the arytenoid cartilages should then be progressively and evenly approximated to each other, until they are firmly in contact and the upper medium is fully reached. The female vocal apparatus is then perfect. While single notes of the chest, lower medium and upper medium, contrasted with each other, have different qualities, the voice is even throughout its entire range, and the proper shading called for in musical compositions can be made in any part of the scale. The blending of the male chest-register into the falsetto and of the upper medium into the female falsetto, or true head-voice, is more difficult, but it is not impossible. Theoretically, this must be done by shortening the vocal chords gradually and progressively and not abruptly, unless the latter be required to produce a legitimate effect of contrast.

Even in singing identical notes, there are distinctly recognizable differences in quality between the bass, barytone and tenor, and between the contralto, mezzo and soprano. For the female, these may be compared to the differences in identical notes played on different strings of the violin. For the male, they may be compared to the qualities of the different strings of the violoncello. Falsetto-notes may be compared to harmonics produced on these instruments.

These ideas with regard to the mechanism of the different vocal registers have resulted from a study of these registers, first from an æsthetic point of view; endeavoring then to find explanations of different qualities of sound appreciated by the ear, in laryngoscopic and other scientific observations, and not by reasoning from scientific observations, as to what effects upon the ear should be produced by certain acts performed by the vocal organs. It may be stated, in this connection, that the works of Bach, Beethoven and other old masters were composed, exactly in accordance with purely physical laws,

long before these laws were ascertained and defined, as has lately been done, particularly by Helmholtz.

#### MECHANISM OF SPEECH.

Articulate language consists in a conventional series of sounds made for the purpose of conveying certain ideas. There being no universal language, it will be necessary to confine the description of speech to the language in which this work is written. Language, as it is naturally acquired, is purely imitative and does not involve of necessity the construction of an alphabet, with its combinations into syllables, words and sentences; but as civilization has advanced, certain differences in the accuracy and elegance with which ideas are expressed have become associated with the degree of development and cultivation of the intellectual faculties. Philologists have long since established a certain standard—varying, to some extent, it is true, with usage and the advance of knowledge, but still sufficiently definite—by which the correctness of modes of expression is measured. It is not proposed to discuss the science of language, or to consider, in this connection at least, the peculiar mental operations concerned in the expression of ideas, but to take the language as it exists, and to describe briefly the mechanism of the production of the most important articulate sounds.

Almost every language is imperfect, as far as an exact correspondence between its sounds and written characters is concerned. The English language is full of incongruities in spelling, such as silent letters and arbitrary and unmeaning variations in pronunciation; but these do not belong to the subject of physiology. There are, however, certain natural divisions of the sounds as expressed by the letters of the alphabet.

*Vowels.*—Certain articulate sounds are called vowel, or vocal, from the fact that they are produced by the vocal chords and are but slightly modified as they pass out of the mouth. The true vowels, *a, e, i, o, u*, can all be sounded alone and may be prolonged in expiration. These are the sounds chiefly employed in singing. The differences in their characters are produced by changes in the position of the tongue, mouth and lips. The vowel-sounds are necessary to the formation of a syllable, and although they generally are modified in speech by consonants, each one may of itself form a syllable or a word. In the construction of syllables and words, the vowels have many different qualities, the chief differences being as they are made long or short. In addition to the modifications in the vowel-sounds by consonants, two or three may be combined so as to be pronounced by a single vocal effort, when they are called respectively, diphthongs and triphthongs. In the proper diphthongs, as *oi*, in voice, the two vowels are sounded. In the improper diphthongs, as *ea*, in heat, and in the Latin diphthongs, as *æ*, in Cæsar, one of the vowels is silent. In triphthongs, as *eau*, in beauty, only one vowel is sounded. *Y*, at the beginning of words, is usually pronounced as a consonant; but in other positions it is pronounced as *e* or *i*.

An important question relates to the differences in the quality of the different vowel-sounds when pronounced with equal pitch and intensity. The