Experimental researches into the physiology of the human voice : a memoir / by John Bishop.

EXPERIMENTAL RESEARCHES

INTO THE

PHYSIOLOGY

OF

THE HUMAN VOICE,

A MEMOIR,

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EXPERIMENTAL RESEARCHES INTO THE PHYSIOLOGY OF THE HUMAN VOICE.

THE human voice is a subject of universal interest, and attracts the attention of numerous individuals in every class of society. The facility with which its organs are brought into play, and the perfect ease with which its various tones are produced, are little calculated to convey an idea of the complex and elaborate mechanism by which they are effected, or of the extreme intricacy in which the phenomena are involved. Few perhaps are aware that the subject of the voice has been the cause of more laborious research and hypothetical reasoning, attended with more perplexing results, than almost any other object of inquiry connected with animal physiology.

The term voice is exclusively appropriated to those sounds which are produced by the vocal organs of animals. These sounds are of two kinds, namely, first, the primary inarticulate tones, with all their modifications of character, quality and intensity, including the key or pitch and the whole range of modulation; and, secondly, the interrupted sounds, or voces limitatæ, which constitute articulate language. To the former division of these functions the following observations are chiefly applied.

The difficulties which for more than twenty centuries have obstructed the elucidation of this interesting branch of natural philosophy, may be ascribed to two principal causes.

First, The organs of voice, when anatomically examined, are found to be extremely complex, including portions which perform several of the most important functions of the animal œconomy.

Secondly, The state of acoustic science is not yet sufficiently advanced to estimate all the effects resulting from air in conjunction with a series of elastic bodies in producing sounds.

The former of these difficulties has been in a great measure removed by Albinus, Bichat, Magendie, and others, and the latter has been considerably reduced by the investigations of M. Felix Savart. Many of the phenomena of the voice, however, yet remain unexplained, and abound with subtile intricacies. Several of these which are of fundamental importance, the details of this Memoir will, I trust, tend to illustrate.

The organs which are associated in the performance of the functions of the voice are principally the lungs, the trachea, the

larynx, pharynx, nostrils, and the mouth with its appendages. In reference to the vocal organs, the lungs may be regarded as a receptacle of air for their supply.

The *Trachea* is a nearly cylindrical pipe forming the *Porte-vent* and the connecting link between the lungs and the larynx. Its anatomical structure is well known, but its office, with respect to the voice, has hitherto been very imperfectly understood. It varies in length and diameter with the sex and age of the individual. In the adult male it is about four inches and a half in length, and from six to eight tenths of an inch in diameter: in the female, the length is about four inches, and the diameter from nine to eleven twentieths of an inch. It is open at both ends, for the free transmission of air; its lower extremity having a double embouchure called the bronchia, which diverge at an angle of about fifteen degrees from the axis of the trachea. The areas of the bronchial tubes are collectively greater than that of the trachea, owing to which the condensation of the air in the latter is more rapidly effected, and the voice acquires, according to M. Savart, a roundness and fulness which it would not otherwise have possessed. The important properties of the trachea with respect to the voice are its elasticity, its power of suffering elongation and contraction, as well as of increasing or diminishing its diameter, and the adaptation of its surface to vibrate in unison with the glottis.

The *Larynx* is situated on the top of the trachea, and forms the superior termination of the vocal tube. Its mechanism and functions are exceedingly complicated, and furnish fit subjects both for anatomical and for philosophical discussion. It is the most important organ of the voice, and its structure requires to be well understood before its functions can be satisfactorily explained. Some brief anatomical details will therefore here be introduced. The larynx is a cartilaginous tube situated in the anterior part of the neck, and separated from the cervical vertebræ by the pharynx, within which it has a motion resembling that of the slides of a telescope. Its figure, although difficult to describe with precision, is symmetrical: broad and capacious in its superior chamber, it becomes narrower at its lower termination, where it is joined to the trachea, and presents externally an appearance very dissimilar to its internal conformation.

The frame of the larynx is composed of elastic cartilages, articulated with each other by fibrous and muscular bands in such a manner as to allow a free passage for the transmission of the air in respiration, as well as that mobility which is necessary to the production of the voice. They are five in num-

ber: namely, the *Thyroid*, the *Cricoid*, the two *Arytenoid* cartilages, and the *Epiglottis*.

The *Thyroid**, the largest of these cartilages, lies in the front of the larynx, where it seems both to shield the internal mechanism from injury, and to contribute to its peculiar function. It is composed of two lateral portions united at the mesial line, where they form an angle more or less acute. These lateral surfaces are nearly smooth, and terminate in four borders; the superior connected by ligaments with the os hyoides, and the inferior with the cricoid cartilage; whilst the two posterior borders give attachment to some fibres of the *Stylo-* and *Palato-Pharyngei* muscles, and send off four angular processes, two of which are connected by ligaments with the extremities of the os hyoides above, and two with the cricoid cartilage below.

The *Cricoid Cartilage**, situated at the bottom of the larynx, serves by its annular shape and dense structure to form the solid portion of the vocal tube. It is narrow anteriorly, where it is connected with the thyroid, from which point it becomes gradually larger, and presents posteriorly a broad band, on the most elevated part of which are seen two oblique and convex articular surfaces whereon the arytenoid cartilages rest. Ridges appear on the outside of the cricoid for the insertion of muscles, and its inferior margin is joined by a fibro-cartilaginous membrane to the first ring of the trachea.

The *Arytenoid Cartilages** are two exceedingly irregularly shaped bodies, situated at the posterior, inner, and upper surface of the cricoid; their figure approaches somewhat to the pyramidal and triangular; their posterior surfaces, to which are attached the oblique and transverse muscles, are concave; they have likewise a concave surface anteriorly, especially towards the lower part, where they are contiguous with a corresponding portion of the arytenoid gland. Their internal surfaces are closely connected with the mucous membrane of the larynx: the planes of these surfaces are perpendicular to the axes of their motion, and adapted to approximate closely with each other. They are terminated by three ridges, one internally, the second externally, and the third anteriorly, which last abounds with inequalities. The bases of the arytenoid cartilages have curved, grooved, oval, articular surfaces, which are furnished with synovial membranes; the grooves are directed downwards, and outwards, corresponding with the convex articulating surface of the cricoid. In front of these cartilages are two conical or pyramidal prominences, forming the posterior part of the chink of the glottis; these prominences project over the tube, about four twentieths of

* Fig. 1.

an inch in the male and about three twentieths in the female. At the points of these projections there are often small distinct cartilages, which give attachment to the thyro-arytenoid ligaments. The perpendicular projections of these bodies have also on each of their summits a small, distinct, isolated cartilage united by perichondrium. The arytenoids are endowed with extensive freedom of motion, including a rotatory motion, a sliding one transverse to their axes of rotation, and an oblique tilting motion. They are destined for the attachment of several muscles, whose forces are directed to regulate the movements of the glottis, and the modulations of the voice.

The *Epiglottis** is a fibro-cartilage occupying a position between the summit of the larynx and the base of the tongue. It is articulated to the superior margin of the angle formed by the union of the lateral portions of the thyroid cartilage, and in its passive state stands almost perpendicular, but assumes a horizontal direction when the larynx is raised in the act of deglutition. In form it has been aptly compared to the leaf of an artichoke; and on both surfaces, but more especially on its laryngeal surface, are found numerous minute orifices in which glands lie imbedded. The epiglottis is depressed by two pairs of small muscles called the *Aryteno-Epiglottidei*, and the *Thyro-Epiglottidei*. The effect produced by the depression of the epiglottis on the fundamental key of the vocal tube is somewhat uncertain. Magendie and Mayo† have inferred from the experiments of M. Grenié‡ that the epiglottis prevents the tones of the voice from becoming more acute when they increase in intensity. This hypothesis is however decidedly erroneous§, inasmuch as neither the elevation nor depression of the epiglottis can affect or regulate the vibrations of the glottis.

The *Thyro-arytenoid ligaments*‖, or *chordæ vocales*, as they

* Fig. 4.

† See Mayo's Physiology, p. 334.

‡ " M. Grenié a trouvé qu'on pouvait corriger ce défaut en mettant au-dessus des anches, dans le tuyau vocal, des petites lamelles de papier, fixées seulement par leur base, et qui, s'élevant quand le courant s'accélère, s'abaissant quand il se ralentit, peuvent, par ces positions diverses, modifier les ondulations de manière que le ton reste constant, avec une intensité de son différente."—*Précis Élémentaire de Physique Expérimentale*, par J. Biot, page 399.

§ According to Liscovius (p. 34.), neither its depression, its elevation, nor even its entire removal have any effect on the voice. Haller (*loc. cit. El. Physiol.* lib. ix. p. 572,) appears also to be of the same opinion: " Epiglottis equidem nihil facit ad vocem; cum ea (vox) nata sit et perfecta quam primum aer ex glottidis rima prodiit et absque epiglottide aves suavissime canant."

‖ Fig. 2.

are commonly (though improperly) denominated, are composed of fasciculi of parallel fibres arising from the bases of the arytenoid cartilages; thence proceeding forwards and inwards, they meet, and are inserted together into the posterior surface of the thyroid cartilage at the junction of its alæ. These ligaments are immediately after death almost transparent, and nearly inelastic. These characters are, however, very soon altered by exposure to the air, and they become opaque and yielding. Their length on an average, in the adult male, is six lines, and in the female four lines and a half. The chink formed by the separation of these ligaments is the *Rimula Glottidis*. The form of this chink in a state of relaxation is elliptical, but when the cartilages are widely separated it assumes the form of an isosceles triangle. The breadth of the chink when relaxed is about three lines.

The movements of the larynx are effected by two sets of muscles; the one attached principally to the *os hyoides*, which is the centre of motion of all these parts, serves to raise and depress the vocal tube; the other is destined to control the movements of the cartilages and internal mechanism of the larynx. The muscles which elevate the larynx are the *Thyro-*, *Mylo-*, *Genio-*, and *Stylo-Hyoidei*, aided by the *Digastrici*. In this elevation the *Genio-glossi*, the *Lingualis*, the *Stylo-*, *Thyro-*, *Crico-*Pharyngei*, and the *Hyo-glossi* concur. The muscles which have an opposite effect, and lower the larynx, are the *Sterno-Thyroidei*, the *Sterno-Hyoidei*, and the *Omo-Hyoidei*.

The second set of muscles exerts a very important influence on the voice, the functions of which being imperfectly understood will require a few details.

The *Crico-thyroideus* † muscle approximates the cricoid to the thyroid cartilage anteriorly, and closes the chink between them. In this action, the posterior and upper edge of the cricoid is rotated backwards, by which the antero-posterior diameter of the larynx is enlarged, and the tension of the vocal ligaments increased.

The *Crico-arytenoideus posticus* ‡ is situated on the posterior broad surface of the cricoid cartilage, whence it originates. Its fibres, ascending obliquely outwards, are attached to the base of the cricoid cartilage, between the *crico-arytenoideus lateralis* and the *arytenoideus obliquus* and *transversus*. This muscle, by drawing the arytenoid cartilage backwards and rotating it outwards, opens the aperture of the glottis.

The *Crico-arytenoideus lateralis* assists in closing the glottis.

* Names given to some fibres of the *constrictor pharyngis inferior*.

† Fig. 7. ‡ Fig. 2.

The peculiarity of the action of this muscle is, that by drawing the external angular base of the arytenoid cartilage forwards, its anterior pyramidal projection, to which the vocal chords are attached, is at the same time rotated inwards.

The *Thyro-arytenoideus* is the most complicated, most important, and the least understood of any of the whole set. It forms the whole superior and inferior lateral boundary of the glottis, and is closely connected with the vocal ligaments; its direct tendency is to antagonize the *crico-thyroideus*, to rotate the cricoid on the thyroid, and to draw forwards and approximate the arytenoids anteriorly, as likewise to relax the vocal ligaments. The thickness of this muscle being increased and rotated upon itself inwards when contracting, forces the edges of the glottis together at its central part. By the various motions of the *thyro-arytenoidei* muscles on the vocal ligaments their edges are turned into the vibrating position, and by their action, in conjunction with that of their antagonists the *crico-thyroidei*, the tension, and the vibrating length of the glottis are regulated. The *thyro-arytenoideus superior* serves to assist the *thyro-arytenoideus* in relaxing the vocal ligaments.

The *Arytenoideus obliquus* and *Aryt. transversus** are muscular bands situated between the two arytenoid cartilages, to which they are attached. Some of the fibres assume a horizontal, others an oblique course, and their united action is to bring these cartilages towards each other, by which the aperture of the glottis is closed posteriorly. It is commonly stated in anatomical works that these small muscles are capable of closing the glottis, but this is incorrect.

The *larynx* is lined throughout by a mucous membrane, which being continued from the mouth, over the epiglottis, forms in its descent those folds over the superior margin of the *thyro-arytenoidei* muscles to which anatomists have given the name of *pseudo-glottis*; thence swelling out into a pouch of considerable size, it forms on either side the ventricle, or *sacculus laryngis*†; and finally, after having been reflected over the *chordæ vocales*, it passes through the cricoid cartilage and becomes the membrane of the trachea. A number of mucous glands are situated in the folds of the pseudo-glottis and in the triangular space at the base of the epiglottis, their excretory ducts opening on that fibro-cartilage. These glands doubtless assist in lubricating the vocal canal.

The *thyroid gland*, a singular substance so named (but in which no excretory duct has been discovered), is placed on the larynx and superior part of the trachea. It is composed of

* Fig. 3.

† The *sacculus laryngis* insulates superiorly the vocal ligaments.

two lateral pyramidal portions, united in most subjects by a distinct glandular medium. Its size varies in different individuals, but is said to be larger in the female than in the male. It has generally been supposed by anatomists that this gland exerts some influence on the voice, but its true functions are unknown *.

The exquisite sensibility of the larynx, its dependence on the will, as well as its muscular motions, are derived from the superior and recurrent laryngeal filaments of the pneumo-gastric nerves. The distribution of these nerves to the muscles which act on the glottis is a subject of anatomical controversy. Experiments made on them by Martin†, Professor Sue of Paris, Dr. Haighton ‡, Cruikshanks, Scarpa, Arnemann, Magendie, and others, have been attended with curious results. The description given of them by the latter however is opposed by Rudolphi, Andersch, Soemmerring, Meckel, Bellingeri and others. The truth is, that the superior and recurrent nerves anastomose in giving filaments to some of those muscles which dilate, as well as to those which close the glottis.

The action of these muscles may be briefly recapitulated as follows: The *crico-arytenoidei postici* open the glottis. All the other muscles close it. The *arytenoideus obliquus* and *aryt. transversus* close the arytenoid cartilages posteriorly. The *crico-arytenoidei laterales* and the *thyro-arytenoidei* close them anteriorly. The *thyro-arytenoidei* close the centre of the glottis, and with the *crico-thyroidei*, regulate its tension, position, and vibrating length.

The views here taken of the actions of these muscles differ from those entertained respecting them by anatomical authors in general. Not having found any two anatomists strictly agreeing on the subject, I have been induced to make numerous dissections to ascertain their functions in producing voice. The annexed figures were drawn by Mr. Henry Dayman, from these dissections. The actions assigned to the *thyro-arytenoidei* admit of most discussion. That these muscles relax the vocal ligaments, and at the same time close the glottis, may at first sight appear exceedingly doubtful; but all my attempts to close the glottis by the approximation of the arytenoid cartilages and the tension of the *crico-thyroidei* muscles

* It appears to me by no means impossible that the thyroid gland secretes a fluid transmitted by some invisible process which lubricates the vocal tube. The constant passage of air must render it requisite that it should be kept permanently moistened.

† Edinburgh Essays.

‡ Mem. of the Med. Soc. of London.

were unsuccessful, nor could any sound be produced until the *thyro-arytenoidei* were brought into action, except by forcing such a volume of air through the glottis as it is almost impossible can take place during life *. In confirmation of this view, it is observed by M. Magendie, that if the *thyro-arytenoidei* are paralysed or their nerves divided, the vocal chords will no longer vibrate. Although there is a great diversity of opinion respecting the actions of the other muscles, they may nevertheless be easily demonstrated on mechanical principles, a task which has been partly accomplished by Mr. Willis.

In reference to their functions, the vocal organs may be regarded as a wind instrument, of which the lungs are the bellows, the vocal tube is the pipe, and the glottis, composed of elastic vibrating membranes, is the reed. The type of these organs is found in all the higher classes of vertebrated animals, in mammalia, in birds, and in reptiles. In fishes it may be considered as rudimental. The production of the most simple tone of voice requires the associated actions of a most extensive range of organs † of which the following is a brief exposition. When the tension of the thyro-arytenoid ligaments takes place they turn upon their axes; their planes (which in a state of relaxation are parallel ‡ to the axis of the vocal tube) become perpendicular § to it, and as the edges of the glottis approximate, its chink is closed up and acquires its true vibrating position ‖. The lungs having first been supplied with air by the muscles of inspiration, and the air in the chest and trachea having subsequently been condensed by the muscles of expiration, a portion of the glottis yields to its

* The quantity of air expelled to produce voice of ordinary intensity is about twenty-five cubic inches in a second in the adult male, with a voice pitched in the tenor G. To produce its grave octave of the same intensity will require 50 cubic inches. In less than ten seconds therefore the lungs will be almost exhausted in producing the upper G, and in less than five seconds in producing its grave octave; allowing 200 cubic inches to be expelled, which is the average quantity of air the lungs are estimated to contain after a full inspiration. The quantity of air expelled from the lungs will consequently vary with every note in the scale relatively with the key and the intensity of tone.

† In the ordinary modulations of the voice more than one hundred muscles are brought into action at the same time.

‡ Fig. 4.

§ This state of the thyro-arytenoid ligaments is the vocalizing position of Mr. Willis: they will not however vibrate unless their edges (through the medium of the mucous membrane) be approximated, and when thus adjusted, they are in the state which I have denominated the true vibrating position of the glottis.

‖ Fig. 6.

pressure, and the edges are curved upwards so as to be nearly parallel to the axis of the vocal tube, leaving between them a narrow aperture through which the air passes. The tension and elasticity of the vocal ligaments tend to restore them to the plane of the vibrating position, whilst, at the same time, the air is acting in an opposite direction. Between these two forces the edges of the glottis are thrown into vibration, which being communicated to the contiguous air, the sounds of the voice are produced. The relative length of the vibrating surface of the glottis is regulated conjointly by the pressure of the column of air in the trachea, and the tension and resistance of the vocal ligaments. A certain degree of condensation of the air is therefore requisite, the maximum varying with the proportion of the area of the chest to that of the trachea. It is upon these hydrostatic principles that the small muscles which close the glottis are capable of resisting the whole force of the respiratory muscles*.

If a person possessing a deep bass voice be directed to expel his breath in a manner not quite sufficient to yield the lowest possible note, on applying the ear to his mouth a clicking motion is perceived. If the tension and velocity of the air are now increased, the clicking ceases, and a continued sound is produced, but of an exceedingly grave pitch. During the previous state, Dr. Young† observes, "a delicate ear may detect the vocal chords vibrating twenty-six times in a second, or about two octaves below the A of a common bass voice."

The intensity of the voice in the same medium‡, and under similar collateral circumstances, depends on the pressure of the column of air in the trachea, and the range of motion performed by the vibrating edges of the glottis. The true vibrating surface of the glottis is the mucous membrane. The vocal chords confer on it the tension, resistance, position, and probably other conditions necessary for vibration. Aphonia often results from undue relaxation of this membrane.

When we consider the fundamental pitch of the human voice, and compare the length of the vocal ligaments with that of

* The force of the expiratory muscles is about a pound on every square inch of the surface of the chest.

† Nat. Phil., vol. ii.

‡ According to Derham, the human voice has been heard at the distance of ten miles at Gibraltar. Boussingault, in his ascent of Chimborazo with Colonel Hall, at the height of 6004 metres (about 19,531 feet), found the voice scarcely audible. The inhalation of hydrogen gas also greatly enfeebles the voice. The intensity of the tone varies reciprocally with the density of the air under similar collateral circumstances.

stringed instruments, or the length of the vocal tube with that of wind instruments, we must at once perceive that the vocal organs vibrate very slowly, simply by their relaxation *, a subject which M. Savart has very successfully demonstrated. The fundamental pitch of the voice will vary as the length of the vocal ligaments, and the power of adjustment in the vocal tube to vibrate in unison with the glottis. This is the cause of infants having acute voices, which gradually become of a graver pitch until they arrive at the age of puberty, when the voice of males assumes an altered character; the pitch suddenly becoming a fifth or an octave graver, attended with hoarseness, and a temporary inability to control and regulate the tones †. During that period, whilst speaking, in the same sentence the voice sometimes becomes suddenly elevated a fifth or an octave; but at the expiration of from eight to twelve months its character becomes finally settled ‡. In the female also, at the age of puberty, the larynx undergoes a change, differing however in kind and less extensive in effect. In the male the whole larynx is enlarged, whilst in the female it chiefly increases in breadth; the junction of the wings of the thyroid anteriorly is at a more obtuse angle, and the prominence of the *pomum Adami* is less conspicuous. The voice at this period acquires a fuller and rounder character, with a greater intensity of tone. In eunuchs a similar but much slighter change takes place.

The natural key or pitch of the vocal organs may be found by sounding the voice without elevating or depressing the larynx; the grave octave of that note will be the fundamental pitch of the voice §. I have frequently tried this experiment on singers, and have always found the hypothesis verified by the result. The pitch of the vocal organs being thus on the con-

* Both temperature and moisture have also very sensible effects on the vibrations of elastic membranes.

† Bennati is of opinion that the voice should not be exercised by singing during this period. The cases of Donzelli and Donizetti (*Recherches sur la Méc. de la Voix Hum.*) admit of a very different construction. It is well known that persons may *acquire* as well as *lose* a good quality of voice after its breaking.

‡ The voice of a person possessing a grave, loud, and reedy character of tone will sometimes yield three or four harmonics of the fundamental note; this was first observed by M. Knecht, of Leipsic. It is singular that by closing the lips lightly, and making them vibrate with the voice, they will simultaneously yield vibrations in harmony with the glottis, but two or three octaves graver in pitch.

§ The tone which may possibly be produced of a graver pitch loses both its quality and intensity, and cannot be considered as belonging to the natural compass of the voice.

fines of the lowest tone of the acute, and the highest of the grave succeeding octaves, occupies a middle or central position, affording a great facility to their actions in varying the tone. In illustration of the advantages of this position, let us suppose the pitch of the voice, in a state of rest, to have been placed at either extreme of the grave or acute termination of these octaves. The vocal tube would then have to pass through very disproportionate spaces. Suppose, for example, the grave octave were C; to arrive at the G of the next succeeding octave the organs would require to ascend a twelfth; or had they been placed at the opposite extreme, to descend a fourth; but as they are now adjusted, it would only be necessary, for the accomplishment of the same tone, to ascend a fifth, or descend a fourth.

The pitch or key of the vocal organs, at the point of rest, is the basis which determines the different characters of voices recognised by musicians. Accordingly we find that what are denominated the bass, the barytone, the tenor, the countertenor, &c. amongst males, and the soprano, mezzo soprano, and soprano sfogato amongst females, are variations of pitch which give an enlarged compass of voice for the purposes of melody, and fill up the musical intervals between the gravest and most acute voices. Ferrein, Fétis, and other French authors have observed that specific characters of voice are peculiar to certain localities. In Picardy, for instance, the finest bass voices occur. Languedoc, and Toulouse, with its environs, are celebrated for tenors; whilst in Burgundy and Franche-Comté, female voices of the first quality are found. No cause has hitherto been assigned for these peculiarities, which do not appear to exist in this country. All these modifications of the voice are dependent on the key of its fundamental tone. We may estimate the average compass of tones comprised between the lowest notes of good bass voices, being about the C string of the violoncello, and the most acute of female voices, reaching C on the second leger line above the G clef, to be four octaves; but there are individuals who can exceed these two extremes. M. Biot calculates three octaves and a half to be the extreme range, but this I know from experience to be too low an estimate.

The power with which the vocal organs are thus endowed, of varying and modulating the grave and acute tones of the voice, has been from an early period a principal subject of inquiry. Aristotle and those who followed him, till the commencement of the last century, were of opinion that the acute tones of the voice depend upon the relative velocity, quantity, and temperature of the air passing through the glottis, com-

bined with the size of its chink *. This theory was adopted by Galen †, Boethius, Fabricius ‡, Marcienne §, Kircher, Perrault ‖, and many others ¶. Dodart ** also at first embraced the Aristotelian hypothesis respecting the velocity of the air in the aperture of the glottis; but finding it insufficient, he adopted a new theory, which, owing to its elaborate researches, has obtained the greatest attention. His theory, however, of the parabolic curves of the glottis, the whistle, and the vox humana pipe of the organ, was by no means a happy deduction from his researches. Ferrein †† has proved by experiment that the vocal chords are capable of yielding all the tones of the voice, and has endeavoured to show that their tension regulates the modulations, and that they are governed by the same laws as stringed musical instruments. Mr. Willis ‡‡ also appears to be of the same opinion as Ferrein with regard to the tension of the vocal ligaments. He observes, "To obtain the various notes from the glottis, therefore, it is only necessary to vary its longitudinal tension after the ligaments have been placed in the proper position." M. Savart, whose valuable researches have contributed greatly to our acoustic knowledge, conceives that the superior and inferior ligaments of the glottis form an apparatus analogous to the duck-whistle §§, and that all the variations of the glottis are regulated upon the same principle as that instrument, a view which has been adopted by several physiologists of the present day.

A consideration of these diversified and unsatisfactory theories induced me to reinvestigate this subject, and for this purpose to repeat the experiments of Ferrein. In the first place, I observed, that in order to produce any sounds whatever, it was requisite to close the chink of the glottis ‖‖, by bringing the edges of the vocal ligaments into immediate contact, when, by straining them tolerably tight, the sounds be-

* ἡ δὲ μεγάλη φωνὴ, γάρ, ἐν τῳ πολὺν ἀέρα κινεῖν, καὶ ὀξεῖα ἐν τῳ ταχέως, βαρεῖα δὲ ἐν τῳ βραδέως.—*Aristotelis Opera*, lib. 2. *Problematum*, sect. xi.

† Galen, *Opera*, *De Larynge*, lib. 7.

‡ *De Larynge, Vocis Organo.* § *Harmonie Universelle.*

‖ *Essais de Physique ; Traité du Bruit.*

¶ Casserius, *De Organo Vocis, &c.*

** *Mém. de l'Acad. Royale*, 1700, 1707. †† *Ibid.*, 1747.

‡‡ Camb. Philos. Trans., vol. iv.

§§ The transverse sections of the larynx in fig. 4. and 5. present an appearance not unlike the duck-whistle, a small circular box, each parallel plate of which is pierced by a small central hole. According to the hypothesis of Savart, the tones of the voice would have resembled those of the whistle rather than those of the reed.

‖‖ Liscovius (*loc. cit.*, p. 29–34.) confirms this remark. He says that no tones are formed where the glottis is very much dilated.

came loud and distinct, but possessing a more reedy quality of tone than belongs to the voice in the living body. The difference was doubtless attributable to the absence of the mouth and nasal cavities, which powerfully influence the melody of the voice. Finding that during the production of sound the chink of the glottis remained closed, excepting the parts in actual vibration, I next minutely observed the change produced in the vocal chords; I remarked that when the gravest tones were uttered, the ligaments vibrated throughout their whole length, and that as the tones became more acute, a proportionably smaller extent of the ligaments was thrown into vibration. During the production of the most acute tones, the tension of the vocal ligaments was but slightly increased, and the greatest possible tension was insufficient to produce acute tones, whilst these ligaments vibrated throughout their whole length. A very slight movement of the thyro-arytenoid muscles seemed to be sufficient to vary the tones, and they would frequently become very acute without my being sensible of having altered the tension. Hence it appears demonstrated that the motions of the thyro-arytenoid and crico-thyroid muscles so affect the vocal chords that a portion of them only is rendered susceptible of vibration. Since therefore a muscular apparatus has been shown expressly adapted to produce all the motions necessary for the modulation of the voice, it may safely be inferred that the phenomena observed in experiments thus conducted actually take place in the living body, and that this is the true mode by which all the tones of the voice, whether acute or grave, are effected *. The ligaments of the glottis being attached at their extremities, are subject, as regards their vibrations, to the laws observed in simple strings, modified perhaps in consequence of the reflection of the mucous membrane over them, owing to which a broad surface is presented to the current of air rather than isolated chords or strings.

Having now considered the manner in which the glottis is made to yield all the fundamental notes, whether acute or grave, of the human voice, I shall investigate the nature of those changes which take place in the vocal tube in order to yield vibrations isochronous with those of the glottis. The intimate relation existing between the glottis and the vocal tube

* The observations of Magendie tend to confirm those deduced from my experiments. He found that the glottis of a dog vibrated in a small proportion of its length during the utterance of acute tones, but in a larger proportion during the grave tones. This fact proves the identity of the motions of the glottis artificially produced in the dead body with those of the living animal.

in which it is placed, the manner in which they are adjusted to each other, and the acoustic effects resulting from this reciprocal action, present an interesting field of inquiry. Although it has been demonstrated that the glottis is capable of producing all the range of tone without the aid of the rest of the vocal organs, its function becomes more limited when placed in the vocal tube, for in that position it can vibrate in perfection only when in unison with the pitch of the tube. When the vocal tube has by any means lost its power of vibrating in accordance with the glottis, the consequence is, that the glottis will either merely reach phonation, produce discordant tones, or become silent altogether. Magendie mentions a person who having a small aperture in the trachea, was obliged to tie a cravat tightly round it, to restore the power of adjustment, and enable him to speak. I lately witnessed an analogous case of loss of voice owing to a fistulous orifice below the glottis. The glottis being situated near the superior extremity of the vocal tube, does not alter the fundamental pitch of the voice; hence Mr. Wheatstone * very justly remarks that the trachea exerts the same influence below the glottis as it would above it †. When the voice is raised in the scale from grave to acute, a corresponding elevation takes place in the larynx, towards the base of the cranium. By placing the finger on the *pomum Adami*, this motion can be easily felt, and at the same time the thyroid cartilage is drawn up within the os hyoides, and presses on the epiglottis; the small space between the thyroid and the cricoid closes ‡; the pharynx is contracted; the *velum palati* is depressed and curved forwards; the tonsils approach each other, and the uvula is folded upon itself §. The reverse of these phenomena takes place during the descent of the voice. These are the principal phenomena which can be recognised by external observation; the other changes being, on account of their situation, invisible.

The effects of these variations on the tones of the voice have been hitherto little understood. It has always appeared incomprehensible why the vocal tube should apparently increase in length in the production of the acute tones, and shorten in the grave ‖, a circumstance which, theoretically, presents an

* See Mayo's Physiology.

† Those physiologists who would assign to the thyroid gland the mechanical office of acting as a damper to stifle the reverberations of sounds in the chest, must have very erroneous notions of the functions of the vocal tube.

‡ Fig. 7.

§ Gerdy (*Bulletin Universel des Sciences,*) remarks, "La luette se racourcit graduellement jusqu'à s'effacer entièrement, lorsque la voix monte très-haut." See also Bennati, *Recherches sur la Voix.*

‖ See Richerand, p. 440.

acoustic paradox. Dodart and many others have conceived the elevation of the larynx to be merely for the purpose of shortening the vocal tube in the super-laryngeal cavity, and have considered the trachea as producing no effect on the key of the tone, an error which has already been pointed out by Mr. Wheatstone. Magendie's remarks on the shortening of the vocal tube apply only to the approximation of the thyroid-cartilage to the os hyoides.

In order to ascertain the effect of these changes, I made the following experiments on the dead body. Having laid bare the vocal organs of an adult male, I raised the larynx to the position it would occupy by the elevation of the voice an octave, being about half an inch, and at the same time minutely observed the position of the lowest ring of the trachea in reference to the sternum. By this operation I found the trachea was raised out of the chest, nearly to the same extent as the larynx had been elevated towards the base of the skull. My next step was to examine whether any change had taken place in the diameter of the tube. Having for this purpose measured the diameter of the trachea in its natural position, I again elevated the larynx to the same extent as before, and found the diameter diminished one third. These experiments prove that, contrary to the general preconception, the elevation of the larynx shortens the tube independently of the contraction between the thyroid cartilage and *os hyoides*, and at the same time lessens its diameter. The same effects may easily be detected during life by placing the finger on the trachea immediately above the sternum during the elevation of the larynx, when the trachea is found to ascend out of the chest, and afterwards to return to its former position, a movement in which the lungs and bronchia participate. The alteration of the tube in diameter may also be perceived by grasping the trachea with the finger and thumb during the elevation and depression of the larynx.

Such are the principal means provided for adjusting the vibrations of the vocal tube to those of the glottis; but as the variation of length is not sufficient to render the tube capable of adjusting itself to the whole range of tones, the relative tension of its surface supplies the deficiency. The influence of the tension of elastic membranes in modulating the tones produced by them has been very satisfactorily demonstrated by the interesting experiments of Savart*, and it is no doubt materially concerned in the analogous phenomena of the voice. The diameter of a tube does not influence the pitch of

* *Annales de Chimie.*

its sound, but there is an obvious appropriateness in the diminution of the diameter of the trachea as the sound becomes sharper; for experience has taught the makers of wind instruments that the best qualities of tone for the lower notes are obtained when the bore of the instrument is large, and for the higher notes when it is small. The influence of the vocal tube, as far as relates to its effects on the key of the voice, is terminated at the *velum palati* by the several perforations of the nostrils, the Eustachian tubes and the mouth. The opinion of Savart, that the mouth modifies the key of the tone is consequently erroneous *. We find analogous acoustic effects in musical instruments; for instance, the lowest joint of the flute, which is six inches in length, having three perforations, when its keys are open lowers the tone of the instrument only half a note. The important distinction between the effects of air passing through the tubes of musical instruments, according as their sides are rigid or membranous, is, that in the former case, as exemplified in flutes, hautboys, &c., the air vibrates independently of the sides of the tube, whilst in the latter, the tube enters into compound vibrations with the column of air.

The falsetto, or *voce di testa*, has always been considered a most embarrassing subject of research, and its peculiar quality has excited the attention both of the physiologist and of the musician. The change produced in the voice when passing from the falsetto into the common tone, or the reverse, is in some persons very sensible to the ear, whilst in others it is almost imperceptible. It is remarkable that some individuals have the faculty of producing, in the same pitch, three or four tones, possessing either the falsetto or the common character, a circumstance which indicates that the difference between them depends rather upon an altered state of the vocal tube than upon any change in the glottis. The falsetto has generally been ascribed to some particular adaptation of the upper ligaments of the larynx. Dodart † has attempted to prove that it is a supra-laryngeal function, and that the nose becomes the principal tube of sound instead of the cavity of the mouth. Bennati ‡ also considers these tones to be modified by the supra-laryngeal cavity, an opinion not justified by the experiments which he has detailed. According to this hypothesis, we must suppose the influence of the trachea to be en-

* Tandis que la bouche en s'ouvrant plus ou moins, et en changeant par consequence les dimensions de la colonne d'air, exerce aussi une influence notable sur le nombre des vibrations, conjointement avec les lèvres.—*Ann. de Chimie*, 1825.

† *Mém. de l'Acad.*, 1707.

‡ *Recherches sur le Méchan. de la Voix Hum.*

tirely annulled; but on what acoustic principle this is to be effected he does not explain, nor indeed can any one else. The changes observed by him in the pharynx were undoubtedly associated with corresponding changes in the whole length of the tube, and all the phenomena he has described may thus be readily explained.

It was suggested to me by Mr. Wheatstone, that it was only necessary to suppose the vocal tube capable of subdividing its vibrating length to account for this peculiar character of tone. Analogous effects are observed in the clarionet, the flute, and other instruments; the change taking place at the twelfth of the fundamental note in the former instrument, and at the octave in the latter. Having had an opportunity of examining the phenomena in some individuals possessing remarkably fine voices, I placed my finger lightly on the larynx, and requested them gradually to elevate the voice from the primary to the falsetto tones, when, although the ear could scarcely distinguish the moment of transition, I found that the larynx suddenly fell, and then continued to re-ascend as the tones became more acute. On observing the motions of the larynx in a mezzo-soprano voice, I found a double falsetto, consisting of several tones of each register, with the power of yielding either the primary or the falsetto character. In this case the larynx fell twice, but in a much smaller degree. An instance of this kind of voice occurs in Miss Lanza. At the moment the larynx falls, during the continued ascent of the tones, the column of air and the tube become divided into portions separated by nodes, yielding harmonics of the fundamental notes, and the modulations of the voice are regulated, as before, by the divided length and relative tension of the tube. A much smaller quantity of air is sufficient to produce these tones; consequently, public singers who chiefly employ the falsetto, suffer much less fatigue than those who use the primary notes. In conducting these observations, care must be taken that the voice do not ascend or descend the scale too rapidly, otherwise the effect may escape detection. In further confirmation of these views it may be remarked, that when the glottis is injured and silenced by disease, the voice is entirely annihilated, which could not be the case if there were any means of producing sound by the superior ligaments of the larynx. There is, however, no doubt that the human voice derives a portion of its peculiar quality from the reverberations of sound in the cavities of the chest and head, modified by every change in these cavities as well as in the vocal tube. The great effect produced by the nasal cavities on the voice is well known.

Much pains have been taken by physiologists to find an

analogy between the organs of voice and artificial musical instruments. Amongst those which have been selected for this purpose are the drum, the duck-whistle, the reed, and various other wind and stringed instruments. These attempts serve to illustrate the complicated structure and functions of the vocal organs; but to me it appears more simple, and at the same time nearer the truth, to consider them in the following point of view: They consist of elastic membranes inclosed in a tube. The glottis is a most complex and beautifully constructed membranous vibrating apparatus, exquisitely adapted for producing all the tones of the voice. The vocal tube, or pipe, is adjusted on the most refined acoustic principles, to yield with the glottis isochronous vibrations. The perfect adaptation of these organs, in a manner inimitable by mechanical art, to produce the most melodious sounds, and to vary them so as to imitate the tones of birds, beasts, and musical instruments, with an almost infinite variety of other sounds, justly excites our admiration and astonishment. Notwithstanding the great labour bestowed by musicians on the temperament of keyed instruments, with a view to correct the dissonances occurring in the construction of the diatochromatic and enharmonic scales, so as to satisfy the ear, such instruments are far inferior to the vocal organs, which can produce all the tones necessary for the most exquisite and perfect harmony. The association of the organ of hearing with that of the voice tends materially to its utility and perfection. Congenital deafness deprives a person of the power of acquiring articulate language, except by a laborious process of tuition, and to a limited extent.

By very slight modifications of the tube the simple uninterrupted tones of the voice will produce the vowel sounds, which have accordingly been imitated by Kratzenstein, De Kempelen, Willis, and others, through the medium of artificial mechanism. The interrupted sounds, or *voces limitatæ*, require, on the other hand, the co-operation of the pharynx, tongue, teeth, cheeks, lips, and nostrils; the various actions of which, by checking the sounds, produce the gutturals, dentals, and labials of grammarians. According to the mode in which the interruption takes place, and to the varied adjustments of the organs employed in effecting them, these are distinguished into mutes, explosives, nasals, liquids, and gutturals: but the manner in which these effects are produced, it is not my present purpose to investigate, and indeed they have been already minutely analysed by Haller, Soemmerring, Blumenbach, Bell, Magendie, Bichat, and others. In the use of articulate language the variations of the voice are usually within a minor third, either above or below the pitch of the vocal

tube, and the inflections of tone are generally in the minor key. When in the vibrating position, the glottis is capable of yielding sounds during inspiration, which are used by some persons for the purposes of ventriloquism. The expressions of pleasure and pain are produced by mere variations of tone, without the aid of articulation. In laughing, the voice is repeatedly interrupted, in consequence of the glottis being alternately opened and closed in quick succession. In crying, the tones follow each other in enharmonic and discordant, but longer intervals.

The views here taken of the functions of the vocal organs, and of which the following is a brief summary, are confirmed both by analogy and by experiment, which, I conceive, afford demonstrative proof of the truth of the theory now advanced, and completely refute those to which reference has previously been made*.

First. The vibrations of the glottis are the fundamental cause of all the tones of the human voice.

Secondly. The vibrating length of the glottis depends conjointly on the tension and resistance of the vocal ligaments, and on the pressure of the column of air in the trachea.

Thirdly. The grave tones vary directly and the acute tones inversely as the vibrating length and tension of the vocal ligaments.

Fourthly. The vocal tube is adjusted to vibrate with the glottis, by the combined influence of its variations of length and of tension.

Fifthly. The elevation of the larynx shortens the vocal tube, and its depression produces the contrary effect. The diameter and tension of the tube vary reciprocally with the length.

Sixthly. The falsetto tones are produced by a nodal division of the column of air, together with the vocal tube, into separate vibrating lengths.

Seventhly. The pitch of the vocal organs, when in a state of rest, is in general the octave of their fundamental note.

In conclusion, it may be remarked that the physiology of the human voice cannot fail to be a subject of interest to every inquiring mind, and many whose names shed a lustre on science have devoted a considerable portion of their time to its

* The hypotheses of Aristotle and Dodart respecting the size of the chink of the glottis must necessarily place the thyro-arytenoidean ligaments out of the vibrating position: the same objection applies to that of Ferrein. The theory of tension requires the glottis to be always open, and vibrating in its whole length, to produce every tone of the vocal scale, a supposition which is opposed both by observation and by experiment.

investigation. The advantages resulting from the study of the voice not only tend to enlarge the sphere of natural knowledge, but also, in a medical point of view, serve as a basis for diagnostic, therapeutic, and pathological inquiry, and consequently contribute to the general benefit of mankind.

Animals far inferior in their organization and intellect to man, are endowed with the power of uttering tones sufficient for the sphere of their existence. The roar of the lion, the lowing of the ox, the song of birds, and the hiss of serpents constitute a natural language which adequately expresses their wants and their passions, and is sufficient for the degree of intelligence belonging to the rank which they occupy in the scale of animal organization.

> " 'Tis sweet to hear the honest watch-dog's bark
> Bay deep-mouth'd welcome, as we draw near home;
> 'Tis sweet to know there is an eye will mark
> Our coming, and look brighter when we come.
> 'Tis sweet to be awakened by the lark,
> Or lull'd by falling waters—or the hum
> Of bees—the voice of girls—the song of birds—
> The lisp of children, and their earliest words."

The human voice may be denominated the music of the mind; language, a figurative mode of expressing our ideas and sentiments. The effects flowing from this beneficent endowment are overwhelming in contemplation and almost infinite in extent. It is principally instrumental to all the moral and physical improvements of man, and enables him to pour forth his otherwise invisible, inaudible, unfathomable thoughts, to his fellow-man and to his God.

Explanation of the Plate.

Fig 1, Is a representation of the larynx, having the left wing of the thyroid cartilage removed, to expose a portion of the internal structure.

a. The right internal surface of the thyroid cartilage.
b b. The arytenoid cartilages.
c c. The thyro-arytenoid ligaments; the mucous membrane being removed.
d. The chink of the glottis.
e e. The posterior crico-arytenoid muscles.
f. The left lateral crico-arytenoid muscle.
g. The cricoid cartilage.
h. The trachea.
i. The membranous and muscular portion of the trachea, which regulates its diameter.

Fig. 2, Is a representation of the larynx, similar to fig. 1, showing the whole of the muscles of the left side at one view. The mucous membrane is dissected away, and the upper edge of the thyro-arytenoid muscle slightly depressed, to expose the ligaments of the glottis.

a, *b*, *c*, *e*, *f*. The same as in fig. 1.
d. The superior thyro-arytenoid muscle.
g. The cricoid cartilage.
h. The thyro-arytenoid muscle.
i k. The trachea.

Fig. 3. This figure presents a section of the larynx, immediately above and parallel to the plane of the glottis. The view is vertical, with the mucous membrane removed to show the mechanism by which the voice is principally modulated.

a. The rimula glottidis in a state of relaxation.
b b. The thyro-arytenoid ligaments.
c c. The thyro-arytenoid muscles.
d d. The lateral crico-arytenoid muscles.
e. The edge of the thyroid cartilage.
f f. The arytenoid cartilages, with their perpendicular projections cut through at *f*.
g. A portion of the transverse arytenoid muscle.
h h. The posterior crico-arytenoid muscles.

Fig. 4. An internal anterior view of the larynx, produced by a section transverse to its antero-posterior diameter.

a. The epiglottis.
b b. The os hyoides.
c c. The segments of the internal surface of the thyroid cartilage.
d d. The thyro-arytenoid muscles.
e e. A portion of the thyro-epiglottideal muscles.
f f. The pseudo-glottis.
g g. The sacculus laryngis.
h h. The cricoid cartilage.
i i. The chordæ vocales, lying nearly parallel to the axis of the vocal tube.
k. The internal aspect of the trachea.

Fig. 5. The posterior segment corresponding to fig. 4.

a. The pharynx.
b b. The arytenoid cartilage invested by its mucous membrane.
c c. The chordæ vocales.
d d. The thyro-arytenoid muscles.
e e. The wings of the thyroid cartilage.
f f. The cricoid cartilage.
g. The trachea.

Fig. 6. This figure represents a transverse section of the larynx: the thyro-arytenoid ligaments are turned perpendicular to the axis of the vocal tube; the glottis is seen in the true vibrating position.

a a. A section of the thyro-arytenoid ligaments.

b b. The pseudo-glottis.

c c. A section of the thyro-arytenoid muscle.

Fig. 7, Is an external side view of the larynx, showing the action of the crico-thyroid muscles, by which the cricoid is rotated with the thyroid cartilage, and the tension of the local ligaments affected.

a. The situation of the insertion of the vocal ligaments.

b. The upper posterior edge of the cricoid cartilage, to which the arytenoids are articulated.

c. The left crico-thyroid muscle.

d. The articulation of the thyroid to the crico-cartilage.

e. The dotted line shows the position of the cricoid cartilage when rotated with the thyroid, whereby the antero-posterior diameter of the larynx is enlarged and the vocal ligaments stretched from *a d* to *a e.*

f. The chink between the thyroid and cricoid cartilages. The dotted line represents the closing of this chink when the cricoid is rotated on the axis of motion of these cartilages at the point *d.*

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