LVI. Experimental researches into the physiology of the human voice

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Teriodide of Gold with Iodides of Sodium and Ammonium.—

These salts are prepared by digesting solutions of the respective iodides on the teriodide. They both crystallize in black four-sided prisms, having much lustre, those containing ammonia being generally flattened. They are both deliquescent, that of sodium so much so that it is obtained in crystals with great difficulty; that of ammonia only in a moist atmosphere. I have not ascertained whether or not they contain any water of crystallization.

The teriodide dissolves also in solutions of the iodides of barium and strontium, giving similar dark-coloured solutions. A solution of the iodide of iron likewise takes it up in considerable quantity, and forms with it a crystallizable compound.

The solution in hydriodic acid has the same dark red colour. Set aside to spontaneous evaporation, it deposits minute black prisms, which, on exposure to the air, acquire a beautiful purple tint, probably from loss of iodine. Whether these are merely crystals of the teriodide, or a compound with hydriodic acid, I have not ascertained. The former is the more probable.

Like the solutions of the terchloride, those containing the teriodide are also decomposed by the addition of caustic ammonia. The precipitate is of a brown colour, more or less dark, sometimes almost black, and, like fulminating gold, it detonates when heated, giving off iodine and ammonia. The dark precipitates are obtained by pouring liquid ammonia into an excess of the teriodide; the lighter, by dropping a solution of the teriodide into caustic ammonia, and agitating at each successive addition. They are decomposed by hot nitric acid, evolving iodine, and leaving a mixture of proto-iodide and metallic gold.

Durham, August 30, 1856.

LVI. *Experimental Researches into the Physiology of the Human Voice.* By JOHN BISHOP, Esq., &c. &c.

[Continued from p. 209.]

THE lungs having been supplied with air by the muscles of inspiration, the ligaments of the glottis are drawn into the vibrating position.

The air in the chest and trachea being now condensed by the muscles of expiration, a portion of the glottis yields to its pressure, and the edges are curved upwards so as to be nearly parallel to the axis of the vocal tube, leaving between them an 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.

The vibration of the edges of the glottis thus produced, by communicating to the adjacent air an alternate state of condensation and rarefaction, the sounds of the voice are accomplished.

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 stringed instruments, or the length of the vocal tube with that of wind instruments, we must at once perceive that the

* 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, found the voice scarcely audible. inhaling hydrogen gas also greatly enfeebles the voice. The intensity of the tone varies reciprocally with the density of the air under similar collateral circumstances.

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 ‡. Eunuchs do not undergo any change of this kind.

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.

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 this hypothesis verified by the result. The pitch of the vocal organs being thus on the confines 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

* 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 (*Recherch. sur la Mec. de la Voix Hum.*) admit of a very different construction. It is well known that persons *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.

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 upon 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, combined with the size of its chink*. This theory was adopted

* ἡ δὲ μεγάλη φωνή, γὰρ, ἐν τῷ πολλῷ ἄερα κινεῖν, καὶ ὀξεία ἐν τῷ ταχείῳ, βαρεῖα δὲ ἐν τῷ βραδείῳ.—*Aristotelis Opera*, lib. 2. *Problematum*, sect. xi.

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, were by no means happy deductions 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-

* 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 figg. 4. and 5. give an appearance not unlike the duck-whistle, which is a small circular box, perforated in the centre by two holes, situated opposite to each other: according to the hypothesis of Savart, the tones of the voice would have rather resembled the whistle than 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.

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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 muscle 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 reflections 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

* 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 illustrates the identity of the motions of the glottis artificially excited, with those of the living animal.

vocal tube 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 phænomena takes place during the descent of the voice.

These are the principal phænomena which can be recognised by external observation; the other changes being, on account of their situation, invisible.

* 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.

‡ See fig. 7.

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

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 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 bronchii 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 superficies supplies the deficiency. The influence

* See Richerand, p. 440.

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 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.

[To be continued.]

LVII. *On the Sivatherium giganteum, a new Fossil Ruminant Genus, from the Valley of the Markanda, in the Siválík branch of the Sub-Himálayan Mountains.* By HUGH FALCONER, M.D., Superintendent Botanical Garden, Seháranpur, and Captain P. T. CAUTLEY, Superintendent Doáb Canal.

[Continued from p. 201, and concluded.]

NOTWITHSTANDING the singularly perfect condition of the head, for an organic remain of such enormous size, we cannot but regret the mutilation at the muzzle and vertex, as it throws a doubt upon some very interesting points of structure in the *Sivatherium*: 1st, the presence or absence of incisive and canine teeth in the upper jaw, and their number and character if present; 2nd, the number and extent of the bones which enter into the basis of the external nostrils; and 3rd, the presence or absence of two horns on the vertex, besides the two intra-orbital ones.

* *Annales de Chimie*.

† 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.