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THE PHYSIOLOGY OF PHONATION

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IT is classical to consider the larynx as having three functions:

1. Respiration;
2. Protection of the pulmonary apparatus;
3. Phonation.

The protection of the pulmonary apparatus is, in reality, the corolla of respiration. As a matter of fact the larynx has a vital function: man cannot live without breathing. The other is social and therefore less important than the previous one, it constitutes the basis of relationship with other people.

The phonation function is not dependent only on the larynx because this organ is not absolutely indispensable. The best example to take is the œsophageal voice of the patient who has had the operation of total laryngectomy.

Sir Victor Negus, by his very attractive researches on the comparative anatomy of the larynx, demonstrates that phonation is bound up with the method of life of animals and that some species are silent and others not. It is a kind of adaptation to the environment, the result of a special organization of the nervous centres and of a specialization of structure already existing.

The study of this physiology is particularly difficult as it is superimposed on a physiology which is not phonatory. In fact, all the organs

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utilized by phonation have also another most important function; respiration and the immobilization of the thorax or protection of the air passages. On the other hand, hearing and vision utilize structures made simply to hear and to see. Just as the voice requires an apparatus able to provoke air vibrations, it also requires and can only exist if there is an apparatus able to receive such vibrations. The apparatus of phonation is consequently dependent on the hearing apparatus. All the species which use their larynx for phonation are those which can also hear. The extreme frequencies of phonation find their place in the tonal scale.

The function of phonation utilizes central nerve structures, nerve tracts and multiple peripheral apparatus among which is the larynx. This is not exactly the vocal organ but just one of the elements of the mechanism of the voice.

However, the vibration of the vocal cords is a fundamental phenomenon among the various peripheral apparatus which are:

(*a*) bellows (tracheo-broncho-pulmonary system);

(*b*) the vibrating constriction (the larynx);

(*c*) the cavities of resonance (pharynx, sinuses, etc.).

Before studying the physiology of phonation it would appear to be indispensable to remember some anatomical details.

The vocal cord is a muscular organ with a fixed insertion, forward to the thyroid cartilage and backward, with a mobile insertion on the vocal process of the arytenoid cartilage. This arytenoid cartilage moves on the cricoid cartilage by means of a joint.

The movements of the arytenoid are produced by the contraction of the dilatory muscle, the posterior crico-arytenoid muscle or posticus fixed on the muscular process of the arytenoid and the posterior part of the cricoid and the constrictor muscle, the lateral crico-arytenoid muscle; the lateral crico-arytenoid muscle is fixed on the vocal process of the arytenoid and on the lateral part of the cricoid ring.

The action of this muscle is completed by the arytenoid muscle fixed on the internal border of both arytenoid cartilages. The contraction of this muscle brings together the arytenoid cartilages to the median line. But the most important muscle of the larynx from the point of view of the physiology of phonation is the vocal cord itself, that is to say the thyro-arytenoid muscle, which is fixed to the arytenoid at the back and to the thyroid at the front.

The structure of this muscle is particularly important. In fact it is made up of two kinds of fibres: the longitudinal ones which are parallel to the membranous vocal cord and the transverse ones described by Kurt Goerttler in 1950. These transverse fibres can be divided into two, the anterior, going from the lateral wall of the thyroid cartilage to the membranous vocal cord and the posterior, coming from the muscular process

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of the arytenoid. The knowledge of these transverse fibres is the basis of the new theory of the physiology of phonation.

The muscles of the larynx are connected to the nervous system by the recurrent laryngeal nerve. The fibres of this nerve follow the path of the pneumogastric nerve arriving in the medulla oblongata at the nucleus ambiguus, forming the first neuron.

The second neuron begins at the level of the nucleus ambiguus, crosses the median line, and arrives in the thalamic brain, while a third neuron goes from the thalamic brain to the cortex at the level of the foot of the ascending frontal convolution.

Myo-Elastic Theory or Tonic Theory

Until recently the physiology of phonation was based on only one theory which is still classical: the myo-elastic theory or tonic theory. According to this, the vocal cords vibrate transversly under the pressure of the tracheal bellows which act like a wedge that separates the vocal cords, their own elasticity bringing them together again.

The frequency corresponds with the equilibrium between the power and the volume of the air-stream and the tension of the myo-elastic contraction.

The cortical and bulbar motor centres of the recurrent laryngeal nerve are only necessary for the glottic contraction and the tension of the vocal cord.

This theory was based on experiments and particularly those of Ferrein in 1731 on a corpse, of Mueller in 1839 with an artificial larynx, and of Lermoyez in 1886, also on a corpse. In my opinion, this theory does not seem to be exact, for many reasons, some of which I will enumerate.

(1) Experiments with an artificial larynx cannot give valuable results, for, to obtain the frequencies of the human voice, particularly the high pitch tones, with such a larynx, it is necessary to use an air-stream and a tension of the vocal cords so intense that they are absolutely incompatible with the physiologic possibilities of the pulmonary bellows and of the human vocal cord.

(2) The same observation can be made for the experiments on a cadaver, because it is necessary to connect the trachea of the cadaver to a bellows much more powerful than the lung.

(3) The singer who uses the falsetto voice, that is to say a high pitch voice, should have a sensation of thoracic strength and of extreme laryngeal tension, but in fact it is a sensation of relaxation that he feels.

(4) This theory does not explain the fact that the vocal cords can vibrate without being close together and cannot vibrate when they are tense and together despite a strong subglottic pressure.

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(5) A probe placed on a vibrating vocal cord does not stop the vibration, whereas, if the vibrations were produced by the air-stream it would stop them.

(6) The "head register" is not so tiring as the "chest register".

(7) This theory does not explain why a singer cannot sing *pianissimo* in high pitched tones.

For these, and other reasons the myo-elastic theory of the physiology of the phonation seems to me to be insufficient.

Clonic Theory

According to this theory the vocal cords have their own vibration. It is not the air-stream which produces the vibration of the vocal cords but the vocal cords which produce vibration of the air.

The vocal cords vibrate transversly by rhythmical stimulation in undulating contractions of the transverse muscular fibres of the thyro-arytenoid, the longitudinal fibres of this muscle having only a tension action.

To produce a sound it is necessary to have pulmo-tracheal bellows and also vocal cords which are close together and vibrating.

This rhythmic contraction of the fibres of the thyro-arytenoid muscle is produced by a nerve action of the same rhythm as that of the recurrent laryngeal nerve with a frequency corresponding to the sound being emitted.

So, with the clonic theory the problem of the vibration of the vocal cords is simply a problem of neuro-muscular physiology and the origin of this vibration must be found in the rhythmic nervous activity of the cells of the encephalon connected with the cortico-recurrential neuron.

Although Oertel, in 1878, with the discovery of the stroboscope saw that the vocal cords vibrate in a horizontal plane, it was only in 1930 that Lindemann had the idea of finding the "action potential" of the superior and inferior laryngeal nerves of dogs while barking.

But it was in 1950 that Raoul Husson, pupil of the French physiologist Lapique, in a thesis delivered to the "Faculté des Sciences de Paris", after many stroboscopic observations, gave for the first time the hypothesis that vibration of the vocal cords is directly commanded by the nervous rhythmic activity, starting from the encephalon, the muscular fibres of the larynx, answering "blow for blow" the recurrential "influx".

It was necessary to verify this hypothesis and many experiments were performed for this purpose: experiments on animals and on men.

I. Experiments on Animals

These were performed by Paul Laget on dogs in the laboratory of physiology of the "Sorbonne" in 1951 and 1952. Paul Laget showed that

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it was possible to observe by stroboscopy vibrations of the vocal cords homorhythmic with the nervous "influx" produced electrically in the recurrent nerve exposed and this without the air-stream.

II. Experiments on Men

(*a*) *On the recurrent nerve*

André Moulonguet, Paul Laget and Raoul Husson tried to prove in 1952 the existence of the "action potential" in the recurrent laryngeal nerve. These experiments were made on patients who had been operated on by total laryngectomy for cancer. After two unsuccessful trials they were able to show, in June, 1953, that the variation of frequency of action potential going along the recurrent laryngeal nerve were almost parallel to the frequency of the emitted sound.

(*b*) *On the vocal cords* (personal experiments)

With Jean-Louis Robin, Paul Laget and Raoul Husson we performed in 1953, 1954 and 1955, in my department of laryngology of the "Hôpital Leopold Bellan" in Paris a series of experiments on patients who had previously been operated on as regards the larynx by a technique permitting approach to the vocal cords in normal physiological conditions and so giving the possibility of their myographic study. Some patients were operated by hemilaryngectomy, others by resection of the base of the tongue by the translaryngeal supra-glottic route.

The active electrode was a needle of Bronk containing two coaxial concentric electrodes connected to an amplifier and oscillating cathode ray tube. The needle was stuck in different parts of the vocal cord in the ligamentous part and deeper, in front, in the middle and at the back of the thyro-arytenoid muscle. The electric activity received was registered and photographed.

1. *Experiments on patients operated on by hemilaryngectomy, half of the larynx having been removed*

One month after the operation it was very easy to see through the opening of the pharyngo-laryngostomy, the vocal cord, the ventricle, and the false vocal cord and so experiments could be made without difficulty. We carried out our researches on the electric activity of the thyro-arytenoid muscle during inspiration and expiration.

(*a*) During each expiration we remarked the contraction of the thyro-arytenoid, translated by a phase of important activity in the electromyogram. The climax is reached in the middle of the phase of expiration. This activity discontinues at the beginning of inspiration and starts again at the beginning of the next expiration.

It is very interesting to note the fact that the climax is reached during expiration, whereas in normal muscular activity of respiration it is reached

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during inspiration, which seems to indicate that it is only due to the activity of the longitudinal fibres.

(*b*) Spontaneous and involuntary tension of the thyro-artenoid during each expiration is independent of every effort of phonation.

(*c*) The motor units constituting the thyro-artenoid seem to be divided into two groups. The first one which is the most important, is constituted by diphasic potential of rather constant aspect and the duration of which is about two milliseconds. The second has the same simple dyphasic morphology. It is shorter in duration, being no more than one millisecond and sometimes less.

The brevity of action potential of the motor units of the thyro-arytenoid muscles and the possibilitity of their being repeated at short intervals requires some comment.

It seems that very few muscular systems having the action potential of motor units of equal or inferior duration to the one we found in the thyro-artenoid muscle, exist in the organism. Only one muscle, the extrinsic muscle of the eye, is known to have this rapidity of action potential.

This brevity is dependent on two chief factors.

(1) An extremely dense motor innervation that signifies motor units which are very small—a great number of muscular fibres each one being innervated by one axon.

(2) The peculiar structure of the muscular fibres.

Goerttler's work showed, in fact, that the muscular fibres of the thyro-arytenoid muscles have a kind of syncytial structure which has no equivalent in the other striated muscles of the body and which brings them nearer the myocardial structure. These results give us a link between the rapidity of the electric phenomena which exist in the vocal cords and the high frequency that they seem to be able to attain during phonation. These researches allow us to explain the relationship between the rapidity of the electric phenomena of the vocal cords and the necessity of extreme velocity of contraction in the closing of the glottic sphincter in order to arrive at a great security margin in the indispensable protection of the airway.

2. *Experiment on patients operated on by translaryngeal supra-glottic technique*

This operation, the technique of which I described for the first time in 1950, aims at keeping the glottis and the functional integrity of the vocal cords intact. It is carried out for the surgical cure of the cancer of the base of the tongue and the epiglottis.

Having removed the superior part of the thyroid cartilage and the hyoid bone one arrives at the base of the tongue and the epiglottis which are resected. The fixing of the mucous membrane of the pharynx and the

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larynx to the skin constitutes a stoma through which it is very easy to see the laryngeal vestibule and the glottic orifice intact. This pharyngostoma is cicatrized in a few weeks and then the patient is in perfect condition for experimentation. The vocal cords are visible in all their thickness and are directly accessible without difficulty.

On the other hand the patient with his own vocal cords so exposed and without any vocal wave passing through the pharyngobuccal cavity can emit lasting sounds of slightly harsh timbre but which have a tonal pitch perfectly definite and recognizable. More than that, the patient can also modulate the emitted sounds and going up and down make a veritable voluntary scale, the emitted sounds being in the octave two approximately between C 2 and B 2.

The electomyography of the vocal cords of the patient was realized during the emission of sounds.

Examination of the oscillographic registrations.—One sees that frequencies are exactly those of the notes emitted by the patient. These registrations show two superimposed phenomena:

(*a*) The first, the chief electric activity of the vocal cord translating its tonic activity.

(*b*) The second, an electrical rhythmic activity with exactly the same frequency as the sound emitted and produced by the motor units in the neighbourhood of the electrode.

The rhythmic stimulations producing contractions of the same rhythm as the motor units during the phonation, as shown on the oscillographic registrations, can have only a central origin.

According to these various experiments the clonic theory is based on the rhythmic contractions of the fibres of the thyro-arytenoid muscle produced by nervous influx coming from the cells of the encephalon and transmitted by the recurrent laryngeal nerve.

The limit of the scale of the laryngeal neuromuscular frequencies are those of the human voice. In low speech this limit is approximately 60 per second, in high speech it is over 1,300 per second (soprano); however, in some exceptional cases this superior limit can be higher. For instance, Mrs. Mado Robin of the Paris Opera, can very easily reach C 6 (2,070 per second) and even D 6 (2,320 per second), a fact which is unique in the world and unique in the history of song.

From the neuro-muscular point of view, the realization of such a scale of frequencies at the level of the larynx raises the double problem: how the recurrent laryngeal nerve transmits such a nervous rhythm, and on the other hand, what is the response?

Polyphasis Recurrential Conduction

Raoul Husson has put forward the hypothesis of the polyphasis of the sound for frequencies below 500 per second, the conduction is without

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difficulty. In this case all the fibres of the recurrent nerve and all the muscular fibres answer "coup pour coup", the order coming from the encephalon. There is monophasis and almost all humans use their first register.

From 500 to 1,000 frequencies there is biphasis, which is when the recurrent nerve and the corresponding fibres of the thyro-artenoid muscle are functionally divided in two parts which work alternatively, one half being in contraction while the other is in a refractory period, and vice versa. All singers use these two registers, mono and biphasia. From 1,000 to 1,500 frequencies there is triphasis, a third of the nerve and of the muscles working while the other two-thirds are in refractory period. Some singers (soprano) use this third register.

Finally, above 1,500 there is quadriphasis, a quarter of the nerve and of the muscle working while the three other quarters are in refractory period. Only two exceptional singers (Mrs. Mado Robin being one of them) can reach the quadriphasis.

This phenomenon of polyphasis is not unique in human physiology, similarly we have the phenomenon for the transmission of the acoustic frequencies in the auditory nerve.

In 1936 Stevens and Davis demonstrated that the monophasis of the cochlear nerve reaches 900 frequencies per second, the biphasis from 900 to 1,800 frequencies per second and so on.

Those are problems of such a complexity that it would be unwise to draw from them too rapid and definitive conclusions.

Origin of the Rhythmic Stimulations

The nervous activity of the recurrent nerve during phonation commanding the thyro-arytenoid fibrillation and the frequency of vibrations of the vocal cord is provoked by the rhythmic activity of the nervous motor elements existing all along the cortical recurrential neuron. This fact is the chief point of the clonic theory as it makes the vibration of the vocal cords part of the physiology of the brain.

The starting point of the rhythmic nervous activity in some part of the cortico recurrential neuron is bound to ionic factors and particularly to the metabolism of calcium and potassium.

There are three levels of stimulation:

The cortex, the diencephalon, and the medulla oblongata.

1. *The Cortex Level*

This level works as a rhythmic stimulator only when the frequency is voluntary, for instance, song and speech at a voluntary pitch. These rhythmic impulses originate in the motor centre at the inferior part of the ascending frontal convolution corresponding to the thyro-artenoid

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muscle. But those encephalic cells are themselves stimulated by the fibres coming from the auditory centre which is the only region of the cortex able to integrate the pitch of the sound and to produce the mental knowledge of the sound.

Although the direct electric excitation of the cortex at the level does not allow us to obtain a local response beyond 40 to 50 frequencies per second, by analogy with the cochlear nerve which at its periphery is able to present action potentials corresponding to frequencies ranging from 4,000 to 6,000 per second to finish at the cortex at frequencies of 75 per second, we can believe that the reverse phenomenon occurs in the motor tract for phonation.

What would seem to prove this hypothesis is that the motor cells in the nucleus ambiguus as the pyramidal cells can already reach the frequency of 100 to 150 per second.

As soon as the sound is produced this simple mental knowledge is completed by the constant control of the frequencies emitted, thanks to the hearing of this sound by the cochlear nerve and the auditory cortical centre.

Several observations of patients examined by laryngo-stroboscopy were published by Ombredanne and bring a confirmation of the cortical action in voluntary phonation. The conclusions of these observations are:

(*a*) In case of unilateral cortical lesion the hetero-lateral vocal cord vibrates very irregularly and the patient loses the possibility of voluntary modulation.

(*b*) If the patient has a bulbar unilateral lesion the homo-lateral vocal cord cannot vibrate but the patient has a weak possibility of voluntary modulation thanks to the integrity of the cortical control which continues to work in the vibration of the opposite vocal cord.

2. *The Thalamic Brain Level*

The thalamic brain intervenes when the frequencies are no longer a voluntary phenomenon, particularly in ordinary speech when one has no desire to produce specific sounds. The thalamic brain is free from the impulses from the cortex and becomes a rhythmic centre.

But we must remember that the thalamic brain is the centre of sentimental life and that it is the point of arrival of many organic afferent actions such as the endocrine afferents and the starting point of vegative afferents.

The result is that the sound pitch produced by the thalamic brain fluctuates, giving to the voice its sentimental character. The examples of this in normal life are numerous: the white voice of fear, the biting voice of the maniac, the dull voice of the schizophrenic, the inability to speak through inhibition due to the thalamic brain which produces hyper-sympathicotomy during a period of emotion.

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In the pathological field, particularly in endocrine affections, we can recall different types of voice:

The perpetual state of vocal emotion in Basedow's disease.

The action of the calcium giving biting voice by tetany due to hyperparathyroidism.

Influence of the sexual hormones, for instance, the virility of the female treated by male hormones for cancer of the breast, etc.

The adrenals and cortico-adrenals stimulate the organism and give mordacity to the voice.

In thalamic syndrome phonation has a moaning character, a kind of lamentation produced by the increase of the sentimental component and diminution of the intellectual component.

The physiology of the "corps strié" intervenes in the hyper or hypotonic aspect of the emotional voice.

The "strio-pallidal" theory of Seemann is, in my opinion, the best explanation which was proposed for an attack of stammering.

3. *The Medulla Oblongata Level*

Larger, Husson and Garde believe that the medulla oblongata can be the rhythmic centre of phonation when it is, in its turn, cleared from the diencephalic impulse. Then, the rhythmic activity comes directly from the auditory impulses forming a simple bulbar reflex arc. In this case, we have stimulation of the ear by a frequency, diffusion of this rhythm at the level of the auditory bulbar nucleus, stimulation of the nucleus ambiguus in its phonic part, stimulation by means of the recurrent nerve of the vocal cord vibrating at the same frequency as the sound emitted.

This phenomenon called "Husson's Cochleo-recurrential reflex" would be the origin of some human phenomena such as Lombard's phenomenon.

This theory of the bulbar action on phonation had been verified by many experiments on animals performed by Husson in the laboratory of physiology of the Sorbonne in Paris, but also by numerous other observations. Many of these observations show the existence of reflective links between phonation and hearing at the level of the medulla oblongata. For example, the deafening of somebody who is speaking does not provoke the same modifications in the intensity and the pitch of the voice if it is performed with a noise producing apparatus (Lombard's test) or with a plug of wax.

Another observation is the difficulty of controlling our own voice when telephoning. Many people shout although the vibrator is placed on only one ear and there is no deafening.

A third observation which seems clinically very important to us is the following: it is possible to produce the auditory stimulation of the voice if we place the vibrator of headphones not on, but behind the ear on the

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mastoid. All deafening, no matter how slight, being eliminated, we have modification of the voice when frequencies of the conversational scale are sent through the vibrators.

The clonic theory that I have just exposed is, in my opinion, very important because with it the larynx is no more a muscular organ with its own physiology, but it enters into the frame of the neuro-muscular physiology.

Then phoniatry is much more than a simple peripheral phenomenon, it becomes a problem of neurology.

Only this conception permits us to devise efficient therapeutics for many troubles of the voice.

However, this new theory of the physiology of the phonation put forward by the French school is not accepted by everyone. Van Den Berg, for instance, thinks that the classical myo-elastic theory is sufficient to explain all the phenomena of phonation without the necessity of the nervous system, and he criticizes the clonic theory.

First, the contraction of the vocal muscle does not produce abduction. Second, hypothesis of polyphasis of the nervous influx does not take into account the difference of length between the two recurrent nerves on the right and on the left. Third, in this experiment of electro-myography he has not obtained the same result as Laget and myself. He has never seen synchronism between active muscular potential and the pitch of the sound.

But it is above all the English School, with the works of Floyd, Negus and Neil, which has discussed with the best arguments the value of the clonic theory.

In a recent work presented before the Collegium Oto-Rhino-Laryngologicum at Bordeaux last September 5th, W. Floyd, Negus, and Neil particularly said:

"Closure of the glottis is attained by co-ordinated action of the sphincteric muscles in which the thyro-arytenoid plays its part; the clonic theory appears to ascribe both opening and closure of the glottis to the same muscle, an attempt being made presumably to suggest independent action of the various groups of interwoven fibres. Pulling apart of the glottis in most mammals, including some primates and members of the cat tribe, could not be attained by this mechanism, since there is no origin of the thyro-artenoid muscle fibres from the lax membranous vocal fold; no conus elasticus, similar to that of man, is present. In man only the lower part of the glottic margins can be separated, as in the thin register.

Furthermore, if puffs of air were allowed to escape through the larynx by purposive muscular opening of the glottis, there would be, during the phase of relaxation, further escape of air, since the relaxed folds would be

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blown apart by the sustained tracheal air pressure; unless there were simultaneous contraction sufficient to keep the glottis closed, the result would be air waste, with a breathy tone, as occurs in cases of paresis. Such a mechanism could not adequately serve either for speech or song.

If, on the other hand, the clonic theory envisages alternate contraction and relaxation of the thyro-arytenoid muscle, with no active muscular opening of the glottis, then the escape of puffs of air would occur during the phase of relaxation under the influence of air pressure in the trachea the mechanism then resembles that of the tonic theory, except that the determination of pitch is unexplained.

It is obvious, by various methods of examination, that the surface of the vocal folds in contact with one another are greater during the production of lower tones than high, as evidenced by the thick and thin registers; and it is further obvious that the differences of apposed surfaces are determined by the number of fibres of the thyro-artenoid muscle in contraction. The clonic theory appears to suggest that not only must the higher centres control the contraction of a number of respiratory, pharyngeal, laryngeal and buccal muscles, but that in addition they must determine the number of fibres of the thyro-arytenoid muscle in action and must, furthermore, provide rhythmical stimulation of certain of these fibres at the appropriate rate, according to the pitch, while others remain in tonic contraction.

The onus thereby thrown on the higher centres seems to be exaggerated; it is sufficiently complicated in phonation by the tonic mechanism and appears to be overwhelming in the clonic theory."

About their electrobiographic experiments the authors said, too: "At frequencies of 50 and 100 c/s a large e.m.g. response followed each stimulus. Even at frequencies as high as 250 c/s we occasionally found the e.m.g. following the rate of stimulation. However, at frequencies of stimulation higher than this there was no obvious relationship between the e.m.g. potentials and the stimulation frequency."

The arguments of these different proponents of the tonic or myo-elastic theory can be discussed.

1. In fact when the recurrent laryngeal nerve of a dog is stimulated at variable frequencies with sufficiently strong electric applications one observes a lump contraction of the constrictor muscles of the larynx which provoke a true tetanization of these and a complete closure of the glottis, placing the vocal cords one against the other.

By this fact it is very difficult to register their movement.

In our experiments Laget sent the stimulation only during a very short time (0·5 seconds) and repeated once at a frequency of one per second.

In these conditions the constriction of the larynx was less strong than

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with a continuous tetanization and permitted an observation more easily of the movement of the vocal cords.

To have, in this field, an absolutely exact experiment man must have the possibility of exciting only the motor nerve going to the thyro-arytenoid muscle alone with the purpose of avoiding all parasitic effects of the constriction of the glottis.

2. On electromyographic experiments on dogs, Robin and Laget observed a very large electric response and perfectly homorhythmic of the excitation to more than 250 per second. They observed too a homorhythmic response with 350 to 500 excitations per second but weak and with a fluctuating amplitude.

The contradictory results of Floyd are probably caused by the different places where the electrode was inserted and because the animals were different (cats and dogs).

3. In man we found electromyographic response of the vocal cords perfectly homorhythmic to 400 per second.

4. The very recent work of Mrs. Krempotitch, Professor of Anatomy at Zagreb, at Asociation Fde pour l'etude de la Phonation et du language (Paris), shows that the difference of length of both recurrent laryngeal nerves is exactly compensated by the thickness that is bigger in the left nerve which is the longer.

5. Piquet and Decroy et Libersa observed two facts particularly important during experiments on man.

(*a*) On account of the frequencies vibration of the vocal cords is independent of the existence or not of the puff of air.

(*b*) The subglottic pressure has no action for the pitch of the emitted sound.

Finally, many very important theoretical objections can be made according to the structure of the vocal cords.

(i) The function of these vocal cords cannot be compared to that of the skeletal muscles. The thyro-arytenoid muscles are inserted into the tendinous free margin and not into a heavy bony lever.

(ii) We saw that the "fusion" of muscles so as extrinsic muscles of the eye carriage 350 per second.

(iii) The histological structure of the vocal cords is very peculiar. The motor unit is very small and the motor innervation is very dense (Goerttler, May, Couteau).

I want to point out that the experiments on animals and on human beings cannot be strictly compared.

Let us not forget that the gift of speech has only been given to man.

In conclusion, you have seen that each one has brought into the discussion of both theories of the physiology of phonation, tonic and clonic, arguments of value.

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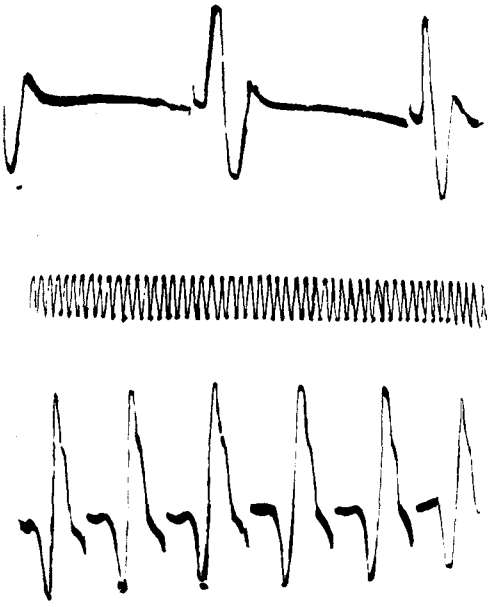


FIG. 1.

Experiments on dogs: Electromyogram of the dog's vocal cord obtained by stimulation of the recurrent nerve, from 25 (above) to 100 (underneath) cycles per second. Between the electromyograms there is a frequency of 1000 c./sec.

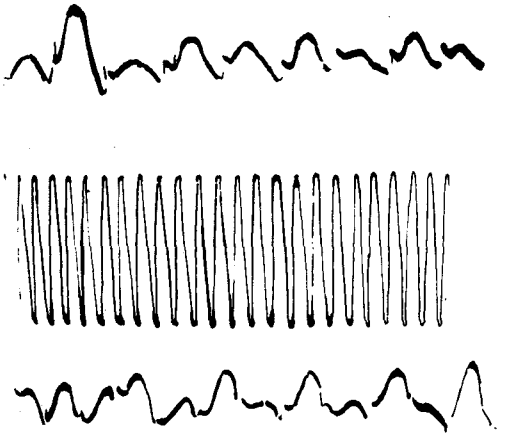


FIG. 2.

Experiments on dogs: Electromyogram of the dog's vocal cord obtained by stimulation of the recurrent nerve, from 300 (above) to 500 (underneath) cycles per second. Note the fluctuations of the responses amplitude. Between the electromyograms there is a frequency of 1000 c./sec.

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I believe that in science, truth is never one-sided. Between the old and the new theories there are many points of contact and in the future we may perhaps see the union of some of them.

It is true to say that our theory cannot explain all the facts, but we must remember that almost all the great discoveries have been anticipations, that is to say, creation of hypothesis, sometimes not verified but which were the starting points of new discoveries.

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