THE EFFECT ON VOCAL PITCH OF THE CONTRACTURE OF THE THYRO-ARYTÆNOID MUSCLES.

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THAT the thyro-arytænoid muscles play an important part in the production of the human voice has long been known. Ambrose Parey (1), who called them the fifth pair of laryngeal muscles proper, describes them as taking part in the dilatation and constriction of the glottis, whereby the vocal sounds become correspondingly low or high in tone.

Up to the year 1700, when Dodart (2) published his first memoir on the human voice, little exact examination into the function of these muscles appears to have been made. Dodart is the first to consider what effect the contracture of the thyro-arytænoids has upon the tension of the lips of the glottis, but he attaches greater importance to the probable effect of that tension on the size of the vocal aperture. It was Ferrein (3) who first gave weight to the tension and length of the vocal cords, as he named the free borders of these muscles, as factors influencing vocal pitch. In more recent times a distinct advance in our knowledge of this subject is due to Müller (4), who, as a result of many series of painstaking experiments upon the recently extirpated human larynx, formulated a hitherto unknown theory as to a double action of the thyro-arytænoid muscles, whereby "vocal compensation" is brought about.

During the last century and, indeed, to-day, such authorities as Magendie (5), Lehfelddt (6), Savart (7), Bennati (8), Willis (9), Bishop (10), Müller (11), Garcia (12), Wyllie (13), Helmholtz (14), Semon (15), Hodgkinson (16), Oertel (17), Mills (18), Morell Mackenzie (19), Lermoyez (20), Castez (21), Curtis (22), Aikin (23), and Perretière (24) differ in opinion as to the manner in which vocal pitch is determined. There appears to be a tendency of observers to attach themselves to one or other of two schools of thought upon this subject, it being maintained on one hand that when the thyro-arytænoids contract the glottis is thereby shortened or the tension of the glottis is increased, and thereby the tone is raised in pitch; on the other hand, that when these muscles contract the vocal cords are slackened or the tension of the glottis is diminished, and of necessity the pitch must fall. The purpose of the present paper is to indicate that whereas the passive lengthening

by external forces of these muscles produces a corresponding rise of vocal pitch, their shortening by active contracture causes the pitch to be lowered in tone, and to show why this must be so, as the result of the physical properties of the muscles concerned. A brief and uncontroversial *resumé* of the physiology of the production of vocal sound may not be out of place. A breath is taken, the glottis is more or less firmly closed, the air inspired is compressed by the action of the respiratory muscles, when the amount of force tending to expel the air from the lungs becomes greater than the constricting force at the glottis, resisting its emission; the latter is thereby momentarily opened and a puff of air escapes; thereupon the pressure in the lungs is diminished, and again the glottis gains the upper hand and closes; so on goes the struggle between these opposing factors, with the result that if these puffs of air are regular in occurrence and follow each other sufficiently rapidly to cause a continuous acoustic impression, then a musical tone results, which will vary in quality according to the niceness of the balance of the two opposing forces.

Whatever be the pitch of the vocal tone produced, the relation of the producing forces will be proportionately the same, while the amount of sound, or its loudness, will correspond to the intensity of the struggle at the glottis. When a larger quantity of air passes out of the glottis at each puff, its velocity will be greater and the amplitude of the vibratory excursions at the glottis will be increased. Thus, from either one or both these factors the sound-waves are rendered more sonorous. If the respiratory force alone is increased, the constriction remaining the same, the note rises in pitch, probably owing to the increased stretching of the edge of the glottis, whereby augmented resistance with quickened recoil and closure of the orifice is brought about, and the note so produced will be harsh and shrill in character, its pitch uncertain and inconstant. A greater expiratory effort would throw the glottis widely open and no phonation would result, a cough or similar sound taking its place. If the amount of constriction alone is varied, as a result of the elasticity of the principle elements concerned, *i. e.* the thyro-arytænoid muscles, the pitch will increase with the elasticity and *vice-versâ*. Should the constriction of the lips of the glottis be sufficient to prevent the exit of air the phonation ceases. It is evident that the state of tension of the vocal cords, *i. e.* of the thyro-arytænoids and vocal ligaments combined, however produced, will influence the pitch of these sonorous vibrations. The vocal cords can only so act in virtue of their inherent properties of elasticity.

An analysis of the constricting force at the glottis shows the glottis flanked by the thyro-arytænoid muscles, which, in virtue of their position, command the egress of air therefrom. These muscles on their free border have the vocal ligaments, which adapt themselves closely to, and follow intimately, the various states of both passive extension and active contraction of these muscles, and thereby serve the purpose of accurately closing and apposing the edges of glottis at each state of tension. Although, as mentioned by Lehfelddt (6), these free edges or vocal ligaments, when the glottis is slightly open, alone vibrate without the muscle participating, and thereby producing what he calls a falsetto, one may neglect this whispered pitch production as not being, strictly speaking, the natural singing voice. Müller has shown that the vocal ligaments alone have a range of pitch which coincides approximately with, although greater in extent than, that of the voice produced by the whole vocal cords, that is, the thyro-arytænoid muscles and vocal ligaments together in ordinary tone production, but that the quality and amount of tone produced by them alone is shrill and little sonorous, while with a more firmly closed glottis the whole breadth of the vocal cords participates in the vibration, and the sound resulting therefrom closely resembles that of the ordinary human voice in timbre and range. Müller found further that the more the thyro-arytænoids were involved in the vibration the louder became the voice without the pitch being raised by an increased expiratory blast, and that conversely that a softer note might be produced when the blast was weaker without the pitch falling; this Müller called "vocal compensation," and deduced it as the principal function of these muscles.

Wyllie (13) found that in the recently extirpated human larynx, on a roll of brown paper being substituted for the thyro-arytænoid muscle of one side a similar effect is produced, and argues from that that the *role* of the muscles is a passive one, but by their presence the vocal pitch is lowered. It was the comparison of the results of the investigations of these last two mentioned observers that led me to look for a reason for this difference of opinion in the subject in the physical properties of the thyro-arytænoid muscles themselves, after having satisfied myself that the elastic vocal ligaments do not in themselves determine the pitch, but follow all movements of the muscular bands, *i. e.* the thyro-arytænoids, and so permit of the clean apposition of the lips of the glottis on phonation. It was evident that the thyro-arytænoids did not by their passive presence alone lower vocal pitch, neither

was the lowering of pitch concomitant with contracture the sole function of the muscles. The muscles must at one time cause the tone to rise, and at another time to fall in pitch. We have seen above that vocal pitch is determined by the present elasticity of the lips of the glottis, therefore the elasticity of the thyro-arytænoid muscles which are contained in them must also vary under different conditions. Now, anything that would throw light upon the causes that are capable of modifying this elasticity would throw light upon the *rôle* of these muscles in the determination of vocal pitch. By the manner in which these muscles are placed at the glottis the issuing air, using the true cords as levers, twists or rotates these muscles about their horizontal axes, thereby causing alternate closure and opening of the glottis. The rate of this oscillation will determine the vocal pitch. The muscles oscillate at a definite rate in virtue of their present elasticity. As the elasticity is increased the vibratory oscillation is relatively increased, and so the pitch rises, and *vice-versâ*. There is no reason to suppose that the thyro-arytænoid muscles differ from other striped muscles in their behaviour under the various conditions about to be noted. A glance at the property of elasticity of striped muscle would enable us to infer how the various conditions met with in the muscle at rest, in active contracture, in passive stretching, and in a combination of both the latter would affect the elasticity of the muscles, in virtue of which they are able to govern the vocal pitch when suitably placed for so doing. This view, therefore, of the property of elasticity of striped muscle, of which the thyro-arytæoids are examples, will indicate in what manner the elasticity of these muscles is actually modified for the purpose of forming and altering the vocal pitch.

If in the after-going description of the properties of elasticity of striped muscle one reads for "striped muscle" thyro-arytæoids, for "increased elasticity" raised vocal pitch, for "diminished elasticity" lowered vocal pitch, for "active muscle" contracture of the thyro-arytæoids, and for "weight" the contracture of the crico-thyroid muscles, it will soon be evident to what conclusions these facts lead us.

The elasticity of the living thyro-arytænoid may be determined by the pitch of its sonorous vibrations, or by means of the laryngostroboscope.

The elasticity of passive muscle is small but complete, and its amount increases with its increased extension. In the living body the muscles are already stretched to a slight extent. The elasticity

of active muscle is diminished as compared with that of passive muscle, and the muscle is lengthened by the same weight to a greater extent than is resting muscle. It is also softer, its apparent increased hardness being only due to its tension. When fatigued its elasticity still further diminishes. The elasticity of active muscle was found by Kaiser (25) to depend upon its actual length at the time. It is least when the muscle has the same length in the active as in the passive state. If shortening occurs in a muscle stretched by a weight its elasticity is *diminished*; this reaches its minimum when the muscle reaches the same length as the passive unweighted muscle. If the active muscle contracts still further its elasticity increases. The elasticity of muscle may be measured by its rate of oscillation when twisted about its longitudinal axis. Applying this to the thyro-arytænoid muscles one finds that they have a dual *rôle* in the production of pitch. When passively stretched by the action of the crico-thyroid muscle its elasticity is increased, and thereby the vocal pitch is raised. When in a state of active contracture its elasticity is diminished, and the pitch falls.

The function of the muscle in the production of pitch and piano and forte notes lies between these two factors of passive extension and active contracture. These factors appear sufficient to account for all alterations in pitch and volume of tone taken in conjunction with the force of the expired air.

From the foregoing the author draws the following conclusions:

(1) That the limit of ordinary singing-pitch lies between two points: (a) When the thyro-arytænoid is stretched by the action of the crico-thyroid muscle to its limit of elasticity, being passively so stretched, *i.e.* the upper vocal limit; (b) when the thyro-arytænoid passes into a state of contracture, shortening being permitted by the diminished opposition of the crico-thyroid.

(2) That the resting thyro-arytænoid, in virtue of its tonicity, gives a pitch of note which will vary accordingly as the muscle is stretched while in that state.

(3) That other things being equal the effect of the contracture of the thyro-arytænoid is to lower vocal pitch.

(4) That the pitch being maintained the amplitude of the sonorous vibrations is increased by its contracture (Müller's "vocal compensation").

(5) That the timbre of a note produced by contracture of the muscle will differ from that produced by its passive stretching, and being richer in the lower harmonics.

(6) That the diminished elasticity of the fatigued muscles would account for "flatness" in a tired singer.

(7) That the pitch of a given note will depend upon the length of the muscle in contracture.

(8) That the lower limit of pitch is reached when the contracting muscle shortens to the same length, as in the state of rest.

(9) That any further shortening due to unopposed contracture of the muscle would cause sudden rise of vocal pitch were it not that the glottis becomes too widely open for this to occur.

(10) The pitch and timbre of notes produced where the stretching predominates over that of the contracture of the muscle would be correspondingly high and clear, *i. e.* as in the "head notes" of the soprano and *vice-versé*, as in the "chest notes" of the bass voice.

In conclusion, it will be evident that if we take all the possible combinations of these two foregoing factors into consideration they are sufficient to account for any known pitch, timbre or "register" of the human voice.

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