THE FUNCTION OF THE BODY DURING SINGING

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Introduction

It was natural that we, a singing teacher and a physiologist, should discuss the role that the body plays in singing during our collaboration over the years as teacher and student of singing. Indeed, this topic has stimulated many discussions as we analysed certain problems in singing, each on the basis of his own background. We have now developed a vocabulary adequate for expressing our common viewpoints, and we want to communicate the results of our discussions, because we feel that this is essential for those studying and teaching singing. We have also suggested new directions for research in the physiology of singing, and it is our intention to establish future joint physiological experiments to test our hypotheses. Though these experiments are yet to be designed, we are convinced that our analysis, by itself, constitutes an independent contribution to the understanding of how to sing in that it combines experiences from singing, teaching, and physiology.

In the literature of vocal pedagogy, descriptions of the function of the vocal cords and of the acoustics involved in singing are common. Very few authors, however, are concerned about the function of the body dyring singing. Vanggaard (1970) cites the exceptions, Rose (1962) and Klein and Schjeide (1967), whose descriptions of the function of the body during singing is similar to ours in certain respects.

We have intentionally omitted a discussion of the function of the body while speaking, as we have become increasingly aware that singing and speaking are different activities in many respects: pitch, sustained pitch, loudness of sound, length and manner of phrasing, articulation, harmonics, and in the exertion of the exercising muscles. Generally speech therapists and physiologists of voice production do not recognize this fundamental difference between the physiology of singing and speaking, and as a result, the scientific approach to the physiology of singing has often come to a dead-end. *We feel that experiences* *from the physiology of speaking are not valid in the physiology of singing without modifications.*

Physiological background.

A knowledge of neuro-muscular function is essential for the thorough understanding of the physiology of singing. To facilitate this understanding the basic principles of this complex subject will be discussed briefly under the following headings: 1) *reflexes,* 2) *conditioning of nerve impulses,* 3) *muscle spindles and tendon organs,* 4) *the organisation and function of the central nervous system (CNS),* 5) *coupling of reflex movements,* 6) *control mechanisms,* and 7) *training.*

1) *Reflexes.* When an external stimulation of a nerve generates an impulse in a sense organ, the result is a series of reflex contractions of different muscles. For example, when the sole of the right foot is pricked with a needle, the result is a combined reflex action: the right leg is flexed, and the left is extended. Impulses travel through nerve fibres from pain-sensitive nerve endings in the sole of the foot to a reflex center in CNS. In the reflex center situated in the spinal medulla, the impulses are transmitted in the following way: a) an excitatory impulse to muscles flexing the right leg (the painful sensation is avoided), b) an inhibitory impulse to muscles which can extend the right leg, c) an excitatory impulse to muscles extending the left leg, d) an inhibitory impulse to muscles bending the left leg, and e) impulses to the cerebral cortex (where consciousness is located) where pain is registered. This example shows that the function of muscles is programmed in complicated patterns. *It is not possible to move one muscle without influencing tension in other muscles.*

2) *Conditioning of nerve impulses* implies that a series of impulses from, for example, the cerebral cortex travelling through CNS to certain muscle groups will facilitate future similar impulses along this neural pathway. Repeated use results in a decrease in the thresholds of the nerve cells involved. *Therefore, adaptations (which are biochemical in nature) in the CNS facilitate a movement during exercise. This conditioning is the physiological background for training and learning.*

3) *Muscle spindles* are small spindle-shaped sense organs, scattered among the ordinary muscle fibres in the ratio of 1:200; this ratio varies between 1:30 in the fine muscles, such as laryngeal and eye muscles, and 1:500 in the big muscles, such as thigh muscles. The muscle spindles consist of 3-6 single muscle fibres surrounded by a helical sensory nerve fibre. The spindles register both actual length and dynamic movement of the muscles. When the muscle spindle is stretched, a nerve impulse is generated to the CNS. The message reaches the

cerebellum (the little brain); but it reaches scarcely, or not at all, the cerebral cortex (the outer layer of the brain). As the consciousness is situated in the cerebral cortex, the notion of muscle tension is not realized by means of these muscle spindle reflexes. Instead the impulses from the muscle spindles travel to the cerebellum, which, as a subordinate part of the CNS, contains a memory for automatic control imposed on every muscle movement; each muscle movement has a specifically programmed pattern. If the muscle contraction follows this programmed pattern, there is no interference on behalf of the cerebellum. However, if the actual movement deviates from the intended one (for example, tripping while walking), this deviation is registered through the muscle spindles. This results in different, not necessarily purposeful, reflex contractions of various muscles. Thus, conversely, impulses from the muscle spindles are necessary for the continuous maintenance of muscle tone (continuous reflex tension = tone). When, for instance, the vocal cords are disturbed in their normal performance (for example, too great an air pressure in relation to the tone in the vocal cord muscles), the result is a decrease of the impulses from the muscle spindles. When the air pressure on the vocal cords is too great in relation to the tone of the muscles, they are momentarily relaxed; this is heard as a "voice break".

Tendon organs are built in very much the same way as muscle spindles; but instead of muscle fibres they contain tendon fibres, and they do not contract. The central pathways from the tendon organs terminate both in the cerebellum *and in the cerebrum.* While acting as sensory organs for the reflex centers in the cerebellum, they also serve as sensory organs for the *conscious awareness of the tension in the muscles.* It is with these organs that it is possible to estimate, for example, the weight of a certain load.

In addition, a special type of modified tendon organ is found in joint capsules; it indicates how much a joint is bent. The vague sensation of tension in the larynx which can be felt occasionally, probably originates in these tendon organs situated in the small crico-thyroid and crico-arythenoid joints.

If the tension in the tendon organs increases above a certain level, a reflex is released relaxing the respective muscle. This is a safety device that protects the tendon from tearing. Again, considering the vocal cords, a forceful pressure on them from below will initiate a similar reflex, and result in a collapse of compression.

4) *The organisation and function of the central nervous system (CNS)* is very complicated. The cerebrum is the superior and chief portion of the brain; it occupies the whole upper cavity of the skull. Here is the seat of the consciousness and the will. Voluntary actions originate in its outer layer, the cerebral cortex; also, sensory impulses to the consciousness terminate here. The little brain (cerebellum) lies behind and below the cerebrum, and occupies the main

part of the lower cavity of the skull. This part of the CNS contains nerve centers for automation and control of muscle contraction and movements. The cerebellum is a subordinate part with no conscious sensations. The cerebral cortex can inhibit the automation of the cerebellum; if the attention of the cerebrum is directed towards an exercised movement, an inhibition will overcome the automation. The nervous singer has difficulties breathing and articulating. If, on the contrary, he has well-trained conditioned reflexes, he will probably perform well. Thus, the nervousness is not able to ruin the performance. *Exercises protect against the detrimental effects of nervousness.*

A ruling principle of the CNS is that nerve centers situated anatomically close to each other have a strong influence on each other. This is essential to the understanding of conditions underlying the physiology of singing. The nerve centers in the lower cerebrum connected to the laryngeal muscles by nerve fibres are very close to those centers connected to the diaphragm. The centers for impulses to the muscles in the neck and shoulders are located somewhat behind this, but are still inside the skull cavity. The corresponding nerve centers for the muscles of the trunk are situated outside the skull, along the entire length of the spinal medulla. Now it can easily be understood that the functional connection between the muscles of the vocal cords, larynx, diaphragm, and shoulders is very close. The muscles of the thoracic and abdominal cavities are comparatively remote. *A functional coupling of the respective muscle groups is the result of the anatomical proximity of nerve centers.*

5) *Coupling of reflex movements* is in fact already explained above, but deserves a special section. Who is not familiar with the gesticulating singer, the pianist, or the cellist who nods his head in time to the music? These gestures demonstrate the interdependency of the different parts of the body: A fist clenches in anger, toes curl in the shoes, shoulders heave, a head is bowed in fear, a body is erect or slouched. This external behaviour is the result of the nerve processes responding to certain stimuli; it is natural, but it is little understood. Variations in individual reactions depend on factors of heredity or environment. Inadvertently a habit is picked up and is never dropped. It is very important to be aware of this when one begins to teach a student to sing. Each student displays a special system of coupled movements, and some of these can possibly be exploited pedagogically. A coupled secondary movement, repeatedly made during singing (nodding the head, furrowing the brow, or moving the arms), should never be interferred with too categorically. The specific secondary movement can be combined with a function of singing, to such an extent that the singing function can disintegrate, if the secondary movement suddenly disappears. Instead the teacher should try to make the most of the secondary movement; others may eventually be invented to distract the student. As the singing lessons progress, other functional secondary movements can be incor-

porated into the act of singing; it is important to discard all non-functional secondary movements.

According to the third point above, the muscle spindles are not involved in the conscious awareness of the laryngeal muscles which include the vocal cords; rather this awareness originates in the tendon organs in tendons and joint-capsules, and it is a common experience that the sensations from larynx and vocal cords are vague. It is evident that the singer does not have the same advantage as the pianist, who is able to control the position of his fingers and hands, and take into account the weight of his arms, etc. For the singer, because his contact with his vocal cords is vague and unprecise, the anatomical and physiological relationships cannot constitute a basis for training conscious sensations which would have to rely on the perception of muscle tensions in the larynx. This understanding of the limitation of the function of the CNS is vital to the singer. He can communicate only indirectly with his vocal cords and send reflex messages to them via certain secondary movements. Only in this way he can indirectly influence the vocal cords to exert the exact tension which matches the actual pressure in the lungs. *The singer is by and large without any awareness of tensions in the muscles of the vocal cords.*

6) *Control mechanisms.* A certain part of the cerebral cortex regulates the function of the larynx with nerve paths, which have fibres which branch off to the cerebellum. These, in turn, assist the automatic control. The ear also exerts control over the voice by a feedback mechanism, which follows nerve paths directly from the center of hearing to the center of the larynx which is in the cerebral cortex. *The most important control function is performed by the ear.*

It is a well-known fact that it is difficult for the student to learn this control. First, it is difficult to concentrate on hearing and singing at the same time; second, one hears his own voice differently than others do; and third, many try to mimic a voice ideal before they have achieved sufficient technical knowledge. In these ways, the student risks inhibiting the natural function of singing. The role of the teacher is, in this respect, crucial, and the confidence between teacher and student is extremely important from the very beginning of singing instruction. Further, a shyness in singing is predominant in our western culture. Students of singing are extremely sensitive to negative criticism, as is anyone who exposes his innermost self. These basic conditions are related to mental inhibitions which are developed in the individual during the years of childhood and adolescence. It demands a great deal of tact and insight on the part of the teacher to bring the true personality of the singing student out from beneath the protecting layers of a complicated defence mechanism which appears at his first singing lessons.

The student has to practise his ear as a control organ with the guidance of the teacher, and the teacher has to work on the disintegration of the inhibitory secondary movements and control functions that are present in the student's reaction pattern while singing. A good microphone and stereo amplifier with echo and two sensitive loudspeakers can be an aid in training the ear. In this way the sound is amplified and rules out the student's listening to his own voice internally so that he hears his own voice more like others do. He thus more easily obtains the desired equilibrium between compression and support, and experiences the important connection between physical sensations and the sound he hears.

The first priority in teaching is to instill the correct use of body and voice; singing "beautifully" is of less importance in the very beginning. After a while the student will learn to measure the relative importance of these two aims, and with the aid of his ear he will be able to use his body and will gradually eliminate unnecessary (and harmful) tensions in the larynx. It must be added here that it is of great help to control the larynx with fingers by moving it sideways if it is loose during phonation. *The goal of the singer is to use aural control exclusively, and if useful, to supplement that with sensations of vibrations or resonance in the chest and head.*

7) *Training* is the repetition of an action with the aim of achieving a better performance. As can be deduced from the above, the CNS is subjected to training (conditioning). One consequence of training is the change in muscle quality. As the laryngeal muscles have never been subjected to scientific investigations in this respect, it is necessary to observe the results of training other muscles such as arms and legs. Human muscles consist of cross-striated muscle fibres. There are two main types, red and white; they are mainly designed for endurance and strength, respectively. The muscles adapt to the demands during training; for example, it is possible to develop greater endurance in the red fibres and to develop greater strength in the white ones. Applying these findings to the voice-producing muscles, it follows that they also can be trained to greater endurance and strength as a result of local changes in those muscle fibres.

Another observation from athletic training is also of great importance: the functional level must be maintained by training. Without it, the functional capacity of the muscles will decrease, and it takes three to four times as long as the inactive period for recuperation.

A common schedule adopted by endurance athletes involves training until complete exhaustion 3-4 days before competition. Then the competitors only exercise lightly or not at all. The scientific explanation is that exhaustion empties the muscle fibres of their fuel, especially the starch-like carbohydrate called glycogen. If after the exhaustion carbohydrates (sugar, flour products, chocolate) are ingested, glycogen will build up in the muscle fibres to a greater concentration than before. This takes about 3-4 days, and the muscle fibres are now superloaded with fuel on the day of competition. The experiences are similar for the singer during vocal study, and explains why it is ruthless exploitation of an operatic singer if he has to perform a major role more than 2-3 times a week. In addition, it is important not to press the voice to the limit every time during the practice period. No voice can stand that. The result will be over-training and concomitant decrease in the functional capacity. If, however, the demands on the voice are gradually increased over a period of, say, 4 days, exhaustive exercises can be carried out the 4th day. The following day the student may either pause or start again with light exercises, and repeat the 4-day cycle.

The *fatigue* sensed in the vocal cords and the larynx is not necessarily harmful. It is a natural sign that the muscles have reached the limits of their functional capacity. The large muscles in the arms and legs are proportionally more tolerant of fatigue than the small muscles. In principle, though, they all obey the same physiological laws. Training will result in an increase in endurance and strength only if the muscles are exercised to the limit inducing fatigue. If fatigue is taken as a warning, it can be a control and a guide during an exercise program. It is evident that stimulating drugs conceal fatigue, and signals of the coming danger are, therefore, not perceived. The performance continues, but with the most serious consequences.

Fatigue is a badly-defined physiological concept. We know that it is both peripheral and central; it is located both peripherally in the working muscles and/or centrally in the CNS. Peripheral fatigue is dependant by the available fuel as described above, and this depends upon the intensity and duration of recent activity. The CNS component of fatigue relates to variations in the thresholds between the single nerve cells, and it is subject to variations in motivation, degree of nervousness, and other ill-defined mental phenomena. The individual's general state of health, well being, mental equilibrium are additional factors. Just as one can speak about tennis fatigue (tennis demands mental concentration, a high level of muscle coordination and a strong mind) for a tennis player who has played too much, one can also talk about "singer's fatigue". The occurrence of singer's fatigue (a CNS fatigue) should be a warning that the activity should be scaled down or even stopped for a certain length of time. After an intermission the singer will return with renewed strength and feel that he has improved his singing in spite of having performed no exercises. This stands out in contrast to what was mentioned above regarding the functional capacity of muscles following a longer period of inactivity. Peripheral and central fatique thus seem to obey different laws.

In the athlete, fibre sprains (tearing of muscle or tendon fibres and/or small arteries accompanied by a haemorrhage) occur in arm and leg muscles. Similar sprains can occur in the vocal cords of the singer. This tendency increases after the age of 25-30. To prevent this, exercises to soften and warm up the sound-producing muscles should be performed with even greater care through the years.

The above discussion is a short introduction to the physiological principles related to the function of the body in singing. The reader is referred to textbooks of exercise- and training-physiology, e.g., Åstrand and Rodahl (1971).

The following pages contain a description of how we think physiological knowledge combines with our concept of what constitutes the action of singing. As this description constitutes the foundation for future experimental collaboration, it is titled "A hypothesis of the function of singing". After this we discuss the proposed hypothesis in the light of relevant literature concerning singing technique and theory.

A hypothesis of the function of singing.

The above is a résumé of the current knowlegde of the function of the CNS, the physiology of learning and mechanisms of control which govern muscle contractions. This is the basis for our concept of how the body functions in the most appropriate way during singing. We have not emphasized an analysis of the function of the various muscles in the larynx, as we do not think that this knowledge will help the student better understand how to sing. Undeniably, it is a very interesting and intriguing scientific problem, especially in pathological phoniatry. There is a difference, however, between knowlegde of the theoretical functioning of the vocal cord muscles, and the application of this knowledge to a correct use of those muscles. The reason is, as mentioned, that man has not any conscious and differentiated notion of the tension in his vocal cords.

The correct use of the vocal cords involves using other muscles during singing in such a way that conditions for the correct function of the vocal cords are produced. In doing this the above laws for the CNS-muscular function must be obeyed, among which laws those of coupled reflex and secondary movements are the most important for this hypothesis.

There are two main considerations involved in the act of singing: first the air pressure below the vocal cords (i.e., in the lungs) and the variation in it at any moment, and second, the tension of the muscles in the vocal cords, the whole larynx, and the resonance above the larynx. We have decided to concentrate on the first consideration and to some extent omit a discussion of the latter. This is for simplicity's sake and should not be taken as an indication that we do not recognize the importance of the latter problem. But, we are convinced that if the correct pressure in the lungs is produced with certain muscle groups of the trunk, the student is guided towards a correct use of his laryngeal muscles and resonance.

The good professional singer is characterized by scarcely perceptible breathing. It is not that he does not have occasion to use a lot of air in certain situations, but in fact the upper part of the thoracic cavity is lifted in the inspiratory position continuously during singing, and the air is pressed out from the lungs by the abdominal muscles.

The air pressure beneath the vocal cords is produced by the combined action of the laryngeal, vocal, diaphragmatic, thoracic, abdominal, and pelvic muscles. These different muscle groups are subject to the above-mentioned laws for the function of the CNS. The problem is to analyse how these muscle groups are to be used during singing in order to obtain the most productive use of the laryngeal muscles and maintain correct pressure beneath the vocal cords. The first item in this analysis will be inspiration and expiration, and the second is an analysis of expiration during piano- and forte-singing. In the analysis the diaphragm is considered to be the flexible floor of the thoracic cavity; it has the ability to resist and in that way regulate the piston-like force of the abdomen content which tries to squeeze the air out of the thoracic cylinder.

The singer should think of himself as singing from the onset of inspiration, that is, before he produces any sound. This inspiration must be anticipated by elevating the upper ribs (singing position). This movement is independent of any inspiration or expiration. With the uppermost ribs elevated – and there they must remain – he now inspires by contracting diaphragmatic and intercostal muscles. In so doing, the thoracic and lumbar curves of the spine are somewhat straightened. The pelvis is tilted backwards by pushing the pubic region forward and tensing the buttocks. The diaphragm is located centrally in the body; it is domeshaped when at rest, causing the fibre direction of the muscular part of the diaphragm to run very steeply upwards. It is attached to the lower ribs, and when contracted, it consequently lifts the ribs, thereby assisting the intercostal muscles. The contraction also presses down the central tendinous part of the diaphragm which displaces the abdominal content downwards. Thus the abdominal wall is passively pushed forward and the flanks outwards. When the ribs are elevated, the volume of the thoracic cavity increases. If, at the same time, the diaphragm is flattened and lowered an increase in volume of the thoracic cavity is created by the increase in height from diaphragm to top of lungs. This completes the *inspiratory phase;* the singer now has the air for use in singing his phrase. Before the actual sound is produced (the *sound phase)* he quickly passes through a very important moment of tension (the *tension phase)* which only lasts for a fraction of a second; the "abdominal press" is activated, thereby building up the support.

The abdominal press is used during processes such as defecation, vomiting, coughing, sneezing, child birth, as well as in singing. During singing the chest may be compared to the air bag that the bagpiper squeezes with his arm; or to be more specific, the abdominal press corresponds to the piper's arm, and the air in the bag corresponds to the air in the lungs. The glottis remains open at the very beginning of the tension phase. However, all muscles that constitute the walls of the abdominal cavity contract: diaphragm, abdominal muscles, muscles of the flanks, back and pelvic bottom, resulting in increased pressure in the abdominal cavity. (In women a problem may develop after child birth; the female pelvic bottom is larger than the male's, and after child birth weakness of the muscles occurs here. This will weaken the abdominal press – no chain is stronger than its weakest link. Retraining of these muscles is important although tensing the buttocks will compensate for this weakness.)

The pressure in the lungs is slightly lower than atmospheric pressure during the inspiratory phase. This is a condition for the air flow into the lungs. During the following tension phase, no air is moving, and as the glottis is open, the pressure will be the same as surrounding atmosphere. An increased abdominal pressure in combination with an open glottis requires that the diaphragm be very tense in order to withstand this pressure. That is, just before the start of the sound phase the diaphragm is very tense to counterbalance the increased pressure of the abdominal cavity. *The diaphragm thus functions as an antagonist to all other muscles which form the walls of the abdominal cavity; it modifies the effects of the high pressure there. This is the main function of the diaphragm during the singing phase.* At the very start of the sound, the diaphragm begins to give way to the pressure built up in the abdominal cavity. The contraction of the diaphragmatic muscles controls the pressure which is transmitted from the abdominal to the thoracic cavity. If the *diaphragm tenses,* the air pressure in lungs *decreases;* if the *diaphragm relaxes,* the pressure *increases,* provided the vocal cords are in a position of phonation and resists the outflow of air from the lungs. If there is equal pressure in the abdominal cavity during piano singing (low lung pressure) and forte singing (high lung pressure), it follows that during the former there will be greater tension in the diaphragm. There are many indications that this is the most effective use of the pressure of the abdominal cavity; this pressure provides the energy necessary for singing. Clearly then, a constant pressure in the abdominal cavity makes it possible to quickly vary the pressure beneath the vocal cords with a slight shift in the tension exerted by the diaphragm.

The sound phase starts with several simultaneous events: the muscle tension in the diaphragm is lowered; the air in the lungs flows out; the vocal cords are put into the position of phonation; and the expiring air starts to vibrate, producing a sound. This pattern is fundamental to all singing.

As mentioned above, we consider the abdominal pressure to be virtually constant during singing, whether the tone is piano or forte, or the pitch high or low. But, the air pressure of the lungs varies considerably. Piano sounds are sung with a low lung pressure and relatively slow flow of air, while the forte sounds are produced by an increased pressure and a somewhat quicker flow of air from the lungs (pressure and flow vary proportionately).

In conclusion: Due to its antagonistic function, the diaphragm modifies the brute strength of the abdominal press, which tries to push the diaphragm into the thoracic cavity, and displaces the air in the lungs. This pistonlike movement, which regulates the flow of air, is slowed down or speeded up by the diaphragm itself. When the diaphragm increases its muscle tension, the piston is slowed down; when it reduces its tension, the abdominal pressure will force the piston into the thoracic cavity. Depending on the amount of tension in the vocal cords, the air pressure and flow will increase.

It was mentioned that the nerves to the vocal cords, the larynx, the diaphragm, and the muscles of the shoulder girdle originate from nerve centers in the bottom part of the brain and are quite close to each other; they are also not very far from centers involved with perception of hearing and formation of language. This is the reason for the close coupling of these functions. It is also remarkable that the vocal cords and the diaphragm function as the ceiling and the bottom of the thoracic cavity. When the vocal cords are closed, the air in the lungs is trapped between the membranes of the cords and diaphragm. It has been proved that these two membranes co-operate during talking and singing. In the embryonic stage the diaphragm and the muscles of the vocal cords are situated close together, near the parts which become the face and jaw. The lungs develop between the vocal cords and diaphragm, and separate these two muscle groups. Since their nerve centers are still in close proximity, the diaphragm and the vocal cords, although themselves physically remote, still have intimate functional contact.

Thus, physiologically as well as anatomically it is quite obvious that the function of the laryngeal and the diaphragmatic muscles are closely related. Take coughing and sneezing for example. During these activities a reflex inspiration is accompanied by a relaxation of the larynx and pharynx, followed by a constriction during a forceful expiration. Another example is deep inspiration – nostrils and the rest of the upper air passages widen by reflex. The diaphragm – an inspiratory muscle – contracts, the larynx is lowered and opens wide, and the annular muscles in the bronchii relax. During expiration the reverse is true. In bronchial asthma the expiration reflexes are too marked. Those patients inspire freely, but during expiration the bronchii constrict trapping the air which must be squeezed slowly out.

It is important that while singing the vocal cords be permitted to vibrate freely in spite of the simultaneous expiration. This is different from the ordinary reflex pattern of respiration, where inspiration means relaxation, and expiration means constriction of the air ways. The aim during singing (as well as during speaking) thus is to fool the CNS into "believing" that an inspiration is going on while, in fact, the air is being squeezed out of the lungs. In a contradiction in terms it could be described as an inspiring expiration. During this the singer's mind is confronted with the dichotomy of thinking centripetally and centrifugally at the same time. He also has to deceive his own reflexes and the sensory input from the muscle spindles and tendon organs. He lets his diaphragm yield *actively* to the abdominal pressure. Activity, or contraction, of the diaphragm will be taken as inspiration, and is, as a result, accompanied by a relaxation of those muscles constricting the bronchii, pharynx and larynx. At this time the vocal cords will also tend to relax. This must of course be counteracted. The aim of teaching singing is to train the appropriate muscles to maintain the correct tension of the vocal cords so they can function in spite of relaxation of the other muscles, to which they are connected by reflex. The co-ordination between the diaphragm and the constrictor muscles of pharynx and larynx must also be altered so that a decrease in the tension of the diaphragm is accompanied by an increase in the relaxation of the constrictor muscles as, for example, is the case during forte singing. During forte singing the vocal cords are driven by an increased pressure in the lungs, which is obtained by both a partial relaxation of the diaphragm, and a greater compression between the two vocal cords. These cords must be allowed to vibrate freely; they must not be hampered by the surrounding muscles as this will hinder the vibrations and fatigue the cords.

To sum up the rather complex situation of forte singing: 1) Maximal relaxation of all muscles that immobilize the larynx, permitting the vocal cords free mobility. 2) Maximal, or at least nearly maximal, activity of the muscles deciding the firmness, length and compression of the vocal cords. 3) A lightly contracted diaphragm, *activily* yielding to the great pressure from below, thus regulating pressure in the lungs in close co-operation with the function of the laryngeal muscles. 4) Maximal pressure in the abdominal cavity which is produced by all of its muscular walls with the exception of the diaphragm. 5) The pelvis tilted backwards and the spine straightened out. This has the effect of bringing the two ends of the long straight abdominal muscle between the sternum and the pubic bone closer to each other, so that there is no unnecessary stretching of this muscle that might impede the inward movement of the abdominal wall. 6) During the entire period of singing the upper part of the rib cage is lefted and maintained in a position of extreme inspiration.

The difference between forte singing and piano singing is much less pronounced than is commonly believed. We postulate that it is in fact only point 3 which actually is different. Instead of being slightly contracted the diaphragm is more forcibly contracted, and possibly combined with a slight decrease in the tension of the abdominal muscles. This will tend to decrease the abdominal pressure slightly, the balance between the different muscle groups being changed. Evidently, changes also take place in the activity of the laryngeal muscles depending on pitch, quality of sound, etc. We think, however, that those are the physiological conditions for exercising the principle of "egalité" (i.e., an equalisation of the registers to create the sense of one single register. The acoustic explanation is that the voice has similar mixture of harmonics at any pitch or dynamic level). Exercising these principles involves producing changes in the body and larynx during singing which are based on simple patterns of action involving a minimum number of muscles. These conditions are fundamental to the fine balance between the air pressure of the lungs and the muscles responsible for compression.

Discussion

It is difficult for the singer to obtain full control of his instrument because he has no sensations of tension in his laryngeal muscles. We have considered the possibilities open to us: on the one hand we have analyzed the interplay between the muscle function in different parts of the body. On the other hand we have introduced a simple model (piston of diaphragm/cylinder of thoracic cage) to explain now the driving abdominal pressure is modified by the diaphragm and transmitted to the thoracic cavity. The pianist can control the position of his hand and fingers. The singer has got similar possibilities of control, but outside his "instrument". He is confined to controlling the working modes of those parts of his body that he can control by his will, outside his vocal cords.

The concept of the function of the body during singing in which the diaphragm has been stressed as an antagonist to the abdominal muscles and also as a synergist to the vocal cord muscles has not been described extensively before. There are hints in the literature of the first half of the century of the important role of the diaphragm. But it is only recently that the function of the diaphragm has been interpreted as an important element in a greater functional pattern (Klein and Schjeide 1967, Rose 1971, Manén 1974, and Rondeleux 1974).

Bruns (1923) talks in his analyses of singing technique of "coasting" (in German, *Freilauf*) in the voice as a hitherto unknown way of singing. "Coasting" is achieved not through respiration support or forcing of muscles, but through "minimum air" and the "unrestricted motor power of the diaphragm". Repeatedly, Bruns stresses the importance of certain muscle groups being relaxed while he maintains that the diaphragm is the muscle in which the original motor force to drive the "coasting" originates. For him the diaphragm is a new and extraordinary powerful source of sound production. "Coasting" results from allowing this source to play freely, and letting certain tones swell without any definite musical aim. According to Bruns, we recognize the voice as acoustic waves, as it moves up and down, now in great intervals, now in small staccato figures or in sudden completely eruptive and overwhelming fortissimi. Parts of Bruns' work which describe his concept of singing technique agree basically with ours. Bruns' intuitive discoveries are partly in accordance with modern physiological concepts. His concept of "minimum air" (that is to sing with nearly emptied lungs) deserves special comment. It is our experience that good tones are easily obtained when singing with nearly emptied lungs, using only the reserve air which correlates to Bruns' "minimum air". This is undoubtedly due to the abdominal muscles working hard to maintain the necessary air pressure in the lungs when the air volume is low. This produces a favorable tension in the vocal cords, balancing compression and support with an acoustically beneficial effect. This is our experience that to train the voice on the reserve air, especially during staccato exercises, is of great benefit. It is also a fact that on stage many actors effectively use a speaking voice driven by reserve air. If, however, during singing, the use of reserve air is adopted as a ruling pimciple, the singer will find that he cannot complete an entire phrase of song. It is clear that for a long (18-22 sec.) phrase of forte singing the singer must start with the lungs completely filled up with air. But, it is also evident that a full inspiration is not necessary every time. The argument against this singing with filled lungs and a high pulmonary pressure has been that the singer can aquire "big lungs" (emphysema) like some oboists and trumpet players. No such danger exists for the singer. The stress on the lungs sustained by some wind instrument players is much greater, and for a longer period of time, than that sustained by the singer.

The principles for muscle training and piston function of the abdominal muscles described by us is similar to the "stow-principle" *(Stauprincip)* described by Armin (1933). We have no doubt that greater strength and endurance of the voice are only achieved by training with exercises to the limit of – but never surpassing – the physical capacity of the voice. This is, among other things, what we believe the *Stauprincip* contains. However, we shall not discuss Armin's subjective concept of the technique of singing in any more detail.

Forchhammer (1943) mentioned the diaphragm as an antagonist to abdominal muscle function, but did not discover the implications of this antagonistic function, which is that the diaphragm regulates lung pressure.

In 1962 two books on singing technique to consider more closely the function of the diaphragm during singing were published: Klein and Schjeide (second ed. 1967) in the USA, and Rose (second ed. 1971) in Great Britain. Klein and Schjeide mention that the diaphragm is contracted during the expiration in singing, and that this is coupled with reflex contractions of the vocal cords. However, they do not observe the importance of this concept. They maintain, as we do, that the singer must learn to fool his own inborn reflexes to sing correctly, but they do not mention the physiological background for this concept. Nor do they stress the importance of using the inspiration reflexes in order to condition the most appropriate singing reflexes.

It has often been stressed in the literature on singing-instruction and -technique, that the best type of breathing through the nose is like that of smelling a flower: *duft-strømmende* inspiration (Forchhammer 1943). If this is compared with what we say in the present article, it is evident that this concept of breathing as a preparation for singing is quite similar to our description of the reflex pattern displayed during singing.

If the nostrils are kept wide open during singing this will support and reinforce the purposeful reflex relaxation of the muscles in the neck and larynx. To obtain this beneficial dilation of the nostrils many singers tense the upper lip and the cheeks while singing. This has developed into an oddly stiff grinning mimic, which in our opinion inhibits free singing. First, it restrains articulation, and second, a grinning face deprives the singer of the ability to make an adequate mimic demanded by the artistic performance. Also dilation of the pharynx *(Breitspannung)* induced by the imagination of a sleepy yawn, or a domed head, or whatever picture used, has the purpose of achieving the reflex inspiration position so vital for singing. The individual singing teacher is too often religiously devoted to worship one or two physiological principles underlying the complex function of singing. This does not encourage the discussion between singing teachers so important to widen our knowledge of the physiology of singing.

Very much has been written about the "correct" way of singing based on intuition. This has not been altogether wrong, but suffers in general in that it is difficult to describe in print. It is, therefore, a great step forward that recent literature treats the subject using the basic principles of physiology and anatomy in the description of the function of singing. In this connection especially, Rose (1971), Manén (1974), and Rondeleux (1974), stand out. These authors all stress the importance of the function of the diaphragm during singing. We completely agree with Rose's description of the tension in the diaphragm as a moderator against the pressure in the abdominal cavity (the diaphragm tensing during piano singing and relaxing during forte singing). Rose might have stressed that this consideration of the diaphragm is still only an important hypothesis yet to be supported by experiments. Manén and Rondeleux stress the importance of stretching the spine out and tilting the pelvis backwards during singing while at the same time elevating the lower ribs. This also agrees with our concept.

In this article we have tried to describe our concept of how the body functions during singing. By incorporating up-to-date physiological knowledge of muscle training, fatigue, reflexes of the nerve system, the function of the sense organs of muscles, inborn and conditioned reflexes, secondary movements, physics of pressure relationships, etc., we have described the act of singing. We sincerely hope that this article will contribute to the understanding of the importance of basing all future discussions upon clearly-defined principles. Also we hope that these principles will have their foundation in physiology. Finally, it is our purpose to influence the research in physiology of singing to investigate not only the function of the larynx, but also that of the whole body.

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RESUMÉ

Denne artikel sammenstiller fysiologisk viden og pædagogisk erfaring om kropsfunktionen under sang. Især nervers og musklers funktion samt den fysiologiske beskrivelse af træning og kontrol er relevant baggrundsviden. Sangerens træning kan i vid udstrækning sammenholdes med idrætsfolks træning, som baseres på omhyggelig opvarmning og fornuftig og systematisk planlægning. En erfaring har en del sangere fælles med idrætsfolk: op til en stor præstation udtrætter man sig 3–4 dage forinden og holder derefter stort set pause indtil det store slag. Den daglige træning kan med stor fordel opbygges efter samme princip: over en 4–dages periode øger man gradvis kravene *indtil* grænsen af sin ydeevne, og starter så forfra. Træthedssymptomer kan man efterhånden lære at udnytte som kontrolfunktion for sin træning. Af kontrolfunktioner på selve sangfunktionen er den auditive kontrol den vigtigste.

En hypotese om sangfunktionen: Under den ideelle kropsfunktion aktiveres *bugpressen:* bughulens muskulatur og mellemgulvet er kontraheret samtidig i et antagonistforhold, og ved udelukkende at ændre mellemgulvets kontraktion kan man nu regulere trykket i brysthulen og dermed luftstrømmen og stemmens styrke, således at forte fremkommer ved mindre kontraktion, piano ved større kontraktion af mellemgulvet.

Det er vigtigt at stemmelæberne får lov til at svinge så frit som muligt, hvilket de hæmmes i under udåndingen, som reflektorisk medfører sammensnøring af luftvejene. Under indåndingen derimod afslappes luftvejene maximalt, hvorfor det er hensigtsmæssigt at "narre" organismen til at tro, at man under den faktiske udstrømning af luft i sangfasen foretager en indånding. Dette lille bedrag opnås tillige ved den ovenfor beskrevne aktivitet af mellemgulvet, der jo primært er en indåndingsmuskel, samt ved at den øverste del af brystkassen forbliver løftet, altså i indåndingsstilling.

Den fremsatte hypotese i artiklen stemmer overens med nyere litteratur om emnet, som dog sjældent giver tilfredsstillende fysiologiske forklaringer; også visse ældre beskrivelser er inde på de samme tanker.