

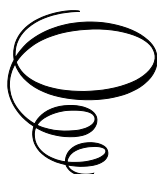
The Scientifically Assisted Evolution of the Professional Singing Voice in Children and Adolescents

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By

Hugo Lycke

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FOREWORD

For many years I worked as a vocal coach/speech and voice therapist for European music conservatories and opera and musical theatre companies, participating as a special member of the jury at many castings, auditions, and rehearsals, testing voices, and providing therapeutic support for conservatory students and professional actors, dancers, and singers (commercial and classic).

This special, creative environment incited me to do my own research on the singing voice. In this exclusive and closed environment - the world of theatre -, not easily accessible for scientific research, I was able to freely experiment and to introduce, little by little, the development of my own methodology of voice classification by phonetography,

I could observe that almost every voice problem, which occurred during the short, but intensive rehearsals, and during the demanding performances on the stage afterwards, primarily had to do with **voice classification**. In my experience as a voice therapist, **phonetographic analysis** proved to be very helpful to all kinds of actors, singers, acting students, singing students, singing teachers, conductors, and directors of contemporary Opera and Musical Theatre.

This original viewpoint has amply been stated by this author, at many international scientific conferences and workshops, and finally resulted, many years later, in a PhD thesis on '**Identification of Three Natural Voice Groups by Phonetography. A data driven approach**', based on an *experimental database of more than 1000 phonetograms*, proving for the first time, *the real existence of three specific natural voice groups for each gender*. Moreover, *a correct classification of a singer's voice proved to be indispensable to achieve an optimum performance and to avoid functional and organic voice disorders*.

Nowadays, this objective and non-invasive method of Voice Range Profiling (Phonetography), improved by modern technology, provides a clear image of all parameters of the speaking and singing voice, visible in real time on the PC screen. Moreover, *longitudinal phonetograms* offer the interesting possibility to document the evolution of a given voice, providing sound

technical advice for voice education and voice therapy.

Since writing my first 3 books, published by Cambridge Scholars Publishing (2022, 2023 and 2024), scientific studies on voice confirm the generally growing appreciation of the usefulness of phonetography in voice testing, education, therapy, and research. However, *studies on the lifelong evolution of the human voice remain rather scarce.*

In this 4th manual, a new approach on the evolution of voice in young children and adolescents, including the complex puberty period, will be proposed, based on an objective voice analysis by phonetography, and providing practical cues for voice education and voice therapy.

I hope that this new book will be useful to anyone interested in this fascinating object of study: the evolution of the voice in children and adolescents.

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INTRODUCTION

The human voice is an amazing phenomenon, comprising many psychological, sociological, artistic and biological aspects. Vocal possibilities and limits are based on individual biological properties. Individual vocal qualities can give rise to optimal and even high-class artistic vocal performances, while vocal restraints can cause functional and organic voice disorders.

Professional voice users, e.g. singers and actors, using their voice as a primary tool, are especially prone to voice problems. Vocal nodules, for instance, most often based on overload of the voice, e.g., due to an *incorrect voice classification*, are well-known in clinical practice. Therefore, it is important in voice and in singing education to know the physiological limits of the voice and to carefully watch them.

My 2nd book, dedicated to the '**Age-Related Evolution of the Professional Singing Voice. Prevention, Voice Testing and Voice Therapy**', provided many specific examples of the vocal evolution of student singers and professionals of both genders from 8 to 88 years old.

This time, special attention will be given to the important voice changes during the complex period of the individual growing process of the voice in young people, including the many influences of personal environment e.g., family, school, and, of course, (singing) education.

In Chapter 1 a survey is given of the different parameters of the voice, as revealed by F⁰-SPL analysis. Chapter 2 analyses the influence of singing education on voice characteristics. The analysis of the results of three questionnaires clarifies how contemporary singing education deals with voice classification (Chapter 3). Chapter 4 explains the importance of voice classification based on phonetographic analysis. In Chapter 5 an analysis is given of our own procedure of F⁰-SPL measurement, followed by a series of statistical elaborated results, as demonstrated by many Tables and Figures, with their interpretation. (Chapters 6, 7 and 8).

Chapter 9 and 10 provide case studies of male and female voices in 2 age groups: under 18 years and 18 to 25 years.

Chapter 11 is dedicated to discussion, while general conclusions are given in Chapter 12.

CHAPTER 1

PARAMETERS OF VOICE REVEALED BY F^o-SPL-ANALYSIS

1.1. Vocal range (= pitch range)

The complex sounds, produced by human beings, are composed of the **fundamental** (the lowest frequency, correlating with the frequency of the glottal opening and closing) and **harmonics** (partials, overtones), which are multiples of the fundamental. ^{1,2}

It is the *fundamental*, i.e., the lowest frequency, which can be analysed in a complex sound, that gives the sensation of *pitch*. **Pitch** is thus the *perceptual correlative of fundamental frequency*.³

Pitch depends on frequency of cord vibrations which depend on:

- a). length, thickness, breadth, and stiffness of the vibrating parts of the cords.
- b). muscle force tending to close the glottis (oppose the cords).
- c). breath pressure.
- d). time relationships of opening, closing and shut phases of vocal cord movements.⁴

Pitch is also dependent on gender, the laryngeal structure, the tension of the larynx musculature and the *voice category*.⁴

Loud voicing at high pitches in speaking and in singing is known to be very demanding.

The measurement of pitch and intensity, as expressed in the phonetogram, clearly indicates the complex relationship between these two most important parameters of voice.

In singers, pressure is adapted not only to phonatory loudness but also to fundamental frequency. Vocal loudness and voice fundamental frequency

are normally interdependent; on the average, speakers and singers raise their average speaking pitch by about 0.4 semitones per dB increase in equivalent sound level.⁵⁻⁶

Every human being can produce a variety of tones which is called the *vocal range*. The possibilities of the singing voice vary along a musical scale, going from C (65 Hz) for some basses to g3 (1566 Hz) or even c4.⁵

The range of sounds most convenient to a voice is called *tessitura*, which is not only different for each *voice category* but also for everyone.⁷

Children between 7 – 14 years can be divided into voice categories too: ⁸⁻¹⁰

- soprano: a – g2.
- mezzo: g – e2.
- alto: f – c2.

Even in very young children the physiological frequency range of the voice has a broad, almost “adult” range.¹⁰

Many authors stress the fact that people’s interest in frequency is limited to a range with a lower value around 16 to 20 Hz and an upper one between 16.000 and 20.000 Hz. This range encompasses normal human hearing.

The sounds of speech are even more limited in range: fundamental vocal cord vibration very rarely extends below about 70 Hz and above 1000 Hz.³

Singing teachers usually evaluate the combination of pitch and vocal quality by ear, thereby excluding some pitches they cannot accept from an aesthetic point of view, whereas scientists generously accept every pitch which the subject’s larynx can produce at a given moment, regardless of its quality.

This controversy easily explains why the few manuals which provide information on the lowest and highest pitches of the human voice differ so greatly, and why there still exists so much confusion between artists, conductors, directors, singing teachers, and even voice scientists, regarding *voice classification*.

As almost everybody feels entitled to make a highly subjective statement on the classification of a given voice, by the sole grace of one’s own supposedly perfect, well-trained, musically tuned two ears, one can easily understand the many misunderstandings on this subject!

Unfortunately, after 60 years of experience in the world of theatre and music conservatories, I must admit that this situation has hardly changed over the years ...

In my opinion, the use of phonetography as *an objective aid in voice classification has been proved to be of great help.*

Frequency range is frequently used as a basic voice classification parameter.

For my doctoral thesis¹¹, I made an explorative study on: “***Frequency Range as a Parameter for Female Voice Classification***”, by means of an algorithm, based on the limits of the female frequency range, according to 38 authors of different backgrounds. The results of the voice classification by the singing teachers were compared to the results of voice classification by the algorithm. The results of the study demonstrated that *frequency range alone proved to be not suitable as a parameter for voice classification.*

In fact, the discussion on *acceptation of a tone* as being inherent of the specific vocal make-up of a subject, or the fear that some tones may be dangerous for someone’s voice, clearly indicates that frequency alone is not sufficient to make a distinction between the voice categories. In fact, I do

believe that in this matter, *voice intensity provides an answer to this age-old discussion.*

1.2. Voice intensity

The voice source can be varied continuously along the phonatory dimensions of *pitch* and *vocal loudness*.³

To understand what voice intensity really means, we must refer to some basic thoughts about this *most important parameter of voice.*

Intensity, as the measure of subjective vocal loudness, is expressed by a logarithmic scale and is proportional to the square of amplitude and frequency. Intensity is also proportional to the square of the pressure and the square of particle velocity.

Sound intensity involves consideration of the rate of flow of energy through a unit area of the medium, a quantity difficult to measure. This is so because the audible range in the basic physical energy units appropriate to this sound attribute is several billion units in extent. Hence it has become a convention

to report not *sound intensity*, but **sound level**; the latter being expressed in ratio units, **decibels (db.)**, rather than the absolute units which appropriately express sound intensity.³

The decibel works to a **logarithmic scale** (exactly as our ears do):

INTENSITY RATIO	DECIBEL EQUIVALENT
1	0 dB
10	10 dB
100	20 dB
1.000	30 dB
10.000	40 dB
100.000	50 dB
1.000.000	60 dB

REMINDER: *a doubling of intensity = 3 dB(A).*

Inverse square law: *SPL dies away by 6 dB(A) every time the distance from the source is doubled.*

In exploring phonetographic results we always must bear in mind that logarithmic scales must be used because of the vastness of these ratios.

It is a remarkable fact that the intensity of very loud speech is roughly a million times that of softly whispered speech.²

There is a range of approximately 140 dB from the threshold of sound detectability to the threshold of pain in the frequency region where hearing is most acute, while the average level of human vocal sounds is about 65 dB above an arbitrarily chosen zero level of 0,0002 dynes per centimetre squared, when the sound measuring instrument is held 1 m. from the speaker's lips.³

Although the human ear is an excellent instrument to quickly detect the nuances of voice quality that still escape the laboratory analyses,¹² *detecting exact loudness differences by ear happens to be far more difficult. This is also the case in the control of dynamic intensity range. **The ear proves to be less susceptible for loudness differences.**⁴*

As Punt⁴ denotes, a person with normal hearing perceives notes of certain pitch ranges as *louder*, than those of other pitch ranges, their intensity being equal. In general, voices sound louder as they range from bass, baritone,

tenor, contralto, mezzo to soprano, partly because of this phenomenon, and partly because the lowest notes can only be sung comparatively softly for physiological reasons. The bass and the lower ranges of the baritone sound especially soft and the higher soprano notes especially loud, but the effect of harmonic partials as well as the fundamental pitch note must be considered.⁴

Ternström¹³ explains how the *dynamic range of a choir* is determined by the skill of the singers, their number, and the room acoustics. Extending the dynamic range of a choir happens to be difficult, as *doubling the number of choir singers only increases the sound level by 3 dB, while a doubling of subglottal pressure of an individual singer raises the sound level by +/- 9 dB.*

According to Murry and Rosen¹⁴, a **cry** produced as a shrieking or screaming sound is the result of increased muscular activity, lengthening of the vocal folds and increased subglottic pressure. Phono trauma, in casu vocal fold haemorrhage, is often the result. Lower SPLs, however, are associated with reduced overall tension in the musculature body of the vocal folds.¹⁵

A study on the speaker's formant in male voices¹⁶ showed that shouting increases the spectral energy of the adjacent critical bands but not the speaker's formant itself. Changes in vocal intensity appear to be directly related to *air flow*.¹⁷

According to Hirano et al.,¹⁸ the regulatory mechanism of the intensity is rather complicated. In general, contribution of the adductors, especially the vocalis and lateral cricoarytenoid muscles, is dominant for low pitches in heavier register, whereas the air flow is more significant for high pitches in lighter register.¹⁸⁻¹⁹

Subglottal pressure is known to be the main physiological parameter for regulating vocal loudness,^{5,20-21, 22,23-33} but several other factors affect SPL.^{23,25,28,33, 34-36} ¹

Plant and Younger²⁹ came to the same conclusion: "In general, intensity increases with higher subglottic air pressures, but there are also considerable variations both between individuals and within different portions of the frequency-intensity range for a given subject".

Keilmann et al.³² came to the same conclusion for children.

Sundberg³⁴⁸ found that singers do not sing more loudly than non-singers, but *singers can be heard even when they are accompanied by a big orchestra if they make use of the “singer’s formant”, a prominent spectrum envelope peak appearing in the vicinity of 3 kHz in all vowel spectra.*

Formant tuning (adjusting the centre of frequency of a formant to coincide with that of a harmonic) and **resonance tuning** (an adjustment of the vocal tract to obtain the desired resonance) have a considerable effect on the singing voice, not only on the quality of the sound but also on the sound pressure level.^{34-35,38,39-40,}

As Carlsson and Sundberg³⁵ expressed it: “the strongest partial determines SPL almost completely; it may be either the fundamental or an overtone, and the amplitude of these partials are varied by different phonatory mechanisms. This appears to be another limitation of the perceptual relevance of the SPL measure”. Moreover, tuning F1 to the vicinity of F⁰ at high pitches is an example of supplementing vocal effort by resonance, as it yields a great gain of sound level at no expense in terms of vocal effort.⁶²

Thus, the relationship between the intensity of the voice source and the radiated SPL is complicated by vocal tract factors³⁸; besides, **mode of phonation** (*from breathy to pressed*) also can affect SPL.⁴¹⁻⁴² To produce more intensity a higher subglottal pressure is needed, and despite this high subglottal pressure, there must be a good glottis closure.⁴²

According to Miller and Schutte³⁹, trying to relate subglottal pressure and mean flow rate to the magnitude of the radiated sound power, may provide an *index of vocal efficiency*.

The modes of vocal fold vibration represent extremes of a *continuum* running *from pressed on the one hand to breathy on the other, with flow in between*. There are many ways to elicit the sound of flow phonation from the singer, while this mode of phonation is more efficient and less physically taxing to the singer.⁴³

In **flow phonation** the flow nearly, but not completely, reaches a true zero flow value.⁴⁴

As Sundberg⁴⁴ stated, “differences in glottal adduction force are relevant to the relationship between subglottal pressure and SPL. If glottal adduction is increased and vibration amplitude thus reduced, more pressure is needed for maintaining the same SPL”.

The various levels of adduction, often described in extremes of “**breathy**” and “**pressed**”, are of great importance from a clinical point of view.^{41,147} The phonatory dimensions pitch, vocal loudness, and mode of phonation (fluctuating between the extremes of hyper functional and hypo functional phonation) are relevant from the point of view of phonatory hygiene as well as from the point of view of vocal pedagogy.⁴⁵

While a not appropriate habitual pitch or vocal loudness can be harmful to vocal health, so does the use of an inappropriate mode of phonation.⁴⁵

The conversational intensity level is 70,42 dB for males and 68,15 dB for females.⁴⁶

Referring to the extensive literature on **vocal nodules**, Lacina⁴⁷ concluded that, *without doubt, vocal nodules in singers develop by vocal strain, forcing, singing in the wrong vocal range, and by vocalizing too loud.*

Heinemann⁴⁸ is of the same opinion regarding the causes of hyper functional voice disorders. *Vocal attrition is associated with the use of increased loudness levels for extended periods of time.*⁴⁹⁻⁵¹

According to Sapienza et al.,⁵² greater tissue damage is possible if increased subglottal pressure is maintained for long durations. In addition to acoustic and perceptual changes, laryngoscopic changes are most likely to be revealed in untrained subjects after 15 minutes to 2 hours of prolonged loud reading.⁵³ Continued use of a high loudness level can lead to further tissue changes such as vocal nodules.⁵⁴

As voice problems in professional voice users result from work-related **vocal load**⁵⁰ **studies** appeared on the effects of vocal loading (prolonged voice use, typically at higher loudness and pitch levels than those used in ordinary speech).^{50,51-55-62}

Winckel⁶³⁻⁶⁵ extensively described the *important influence of room acoustics on the voice*, while Satalof⁶⁶ stressed the many problems of singers performing in large halls, with large orchestras, with lack of auditory feedback during outdoor concerts or accompanied by extremely loud background music.

Long Time Average Spectrum (LTAS) analysis, providing a mean of spectra from all the sounds of a lengthy speech sample, has been reported to be useful in clinical practice since the seventies.⁶⁷⁻⁶⁸

Novak et al.⁵⁹ evaluated *voice fatigue* by means of LTAS measurements in actors after theatre performance. The objective changes they found in the spectrum are caused either by the high vocal effort and physical effort of the performance or by the forcing of their voices and by mental stress.

De Bruyne⁵⁵ explains the pathophysiology of *vocal fatigue* by various forms of vocal misuse: an appropriate pitch and loudness disturbs the balanced functioning of the phonatory muscles as well as the mucosal function. The reduction of intensity is also one of the major symptoms of vocal fatigue.⁶⁹

According to Bennett,⁷⁰ when a singer makes a crescendo, he changes not only the loudness of the note sung, but also its timbre. In particular, the amplitude of the upper formants increases more rapidly than that of the fundamental note as the note gets louder. The singers in his study sang more loudly in the upper part of their range than in the lower, but for each of them the SPL increased amplitude at a different rate and reached its maximum at a different point of the range. He concluded that “not the specific values for any one pitch, but rather *the behaviour of the SPL over the entire range was characteristic and individual for each singer*”.

Hoffman-Rudy et al.⁷¹ studied three categories of professional voice users/vocal performers: musical theatre, choral ensembles, and street theatre. These “*high-risk vocal performers*” produce their singing or theatre voice at their maximum vocal effort level.

In our own study, all our subjects undoubtedly belong to the group of “**high-risk performers**”.

So, voice intensity happens to be a very important parameter of voice, and its exact measurement by phonetography is essential in voice research.

1.3. Voice quality

Moore⁴¹⁸ considers “quality” or “**timbre**” or “**character**” of the voice as “*the auditory impression created by the complexity of the sound wave*”, resulting from the number and relative intensities of the component elements of the sound wave.

An almost unlimited range of different sound qualities is produced by adding overtones to the fundamental note (glottis note). These “**formants**”, shaped by the vocal tract, give the voice sound its typical resonance colour.⁷³⁻⁷⁵

The vibratory characteristics of the vocal folds, in combination with the shape and configuration of the vocal tract, are determining factors for the **quality** of a given voice¹⁸⁹ or, as Sundberg¹²¹ formulated:” ***vocal tract morphology, as reflected by formant frequencies, is relevant to voice quality***”.

According to Winckel,^{63,65} ten to twelve overtones in the voice of professionals and laymen provide a pleasant feeling in listeners. With more overtones the voice sounds shrill and harsh; with less than six overtones, the voice gives a thin, asthenic impression, suggesting already a pathological or ageing voice.

Murphy² prefers to make a distinction between differentiations in ***timbre*** (objectively based, measurable by frequency and intensity spectral analyses) and ***quality*** differentiations, which may be seen as the psychological correlate of resonance and timbre.

To avoid confusion, Delattre⁷⁸ uses “*colour*” for vowels and “*quality*” for voice. As a linguist and experimental phonetician, he considers the acoustic features that characterize vowel colour to be very clear, which cannot be said about the acoustic features that characterize voice quality, either in speaking or in singing.

Michel⁷⁹ considers *voice quality as an amalgamation of phonation, articulation, and resonance*. The way in which these three entities are used is described by the term “***prosody***”, which includes inflection, rate, dynamics, stress, etc.

In the literature **voice quality disorders** have been descriptively labelled in many ways, for instance, as breathy, whispered, aspirate, asthenic, dead, dull, toneless, hoarse, husky, harsh, throaty, raucous, rasping, thin, feeble, hollow, metallic, raspy, rough, coarse, glottal fry, vocal fry, pulse register, crackly, diplophonic, dull, strained, strangled, guttural, shrill, strident, piercing, pinched, thick, tired, weak, unpleasant, muffled, hypernasal, denasal, aphonic, monotonous, vocal tremor and so on.^{2, 80-90}

“**Normal voices**” are labelled too: white, pleasant, warm, round, full, rich, bright, clear, resonant, ringing and so on.^{8,80}

Regarding singing, Miller⁹⁰ states: “*Quality takes on meaning far beyond the harmonic composition of a complex tone and refers to the total impression created by sung tones*”.

Moreover, distinct vocal qualities, as expressed in different vocal styles, such as classical singing, Lied, blues, rock, pop, country & western, crooning, belting, mix, legit, hip hop, and so on, require *specific, cultural dependent and time-bound, vocal adaptations*.^{85, 90-96}

Besides, as Austin⁹⁶ stated: “**there is a wide variety of taste involved in declaring what is good and bad singing**, even within the rather narrow definition of “classical singing in the Western tradition of art song and opera”.

The individual features of voice timbre depend on the individual anatomic variations but also on the speaker’s or singer’s technique, thus “colouring” the voice.^{75,97}

Anno 1940, Bartholomew⁹⁸ wrote: “when voices are used which by accepted artistic standards are satisfactory, these high frequencies will be found rather narrowly limited to range for men between roughly 2400 and 3200, and frequently averaging at 2800 or 2900, and for women a trifle higher “. Many other authors will follow, describing what has been called later: the *singer’s formant*.

For much decennia research has been done on the “**singer’s formant(s)**”, a *clustering of the third, fourth, and fifth formants in the acoustic spectrum*, the famous “**ring**”.^{16,43,63,66,80,97,89-117}

The exact location of region(s) with a maximum amplification,⁹⁸ the width of the formant regions of the singing voice and of the speaking voice,^{98,111-112,230} the gender-factor, and the *classification factor*.⁷⁷ are still questioned. However, general agreement exists on the importance of the singer’s formant as typical for what Rzhhevkin¹⁰⁷ called “*that particular brightness of timbre in good singing voices which is often characterized by the word ‘metallic’ and therefore should be considered fundamental and most important as a sign of a correctly trained singing voice* “. ^{98,110,112,118}

Sundberg^{20,28,37,44, 119-129}, did major investigations on the singing voice. He wrote about the singer’s formant as “*a typical characteristic of voiced sounds sung by male opera and concert singers*”. Other researchers detected analogue characteristics in student singers’, in choir singers, in non-singers’ and actor’s voices, in Jewish cantors, but not in country singers’ voices.¹³⁰⁻¹⁴¹

In fact, a good voice with carrying power exhibits strong spectrum partials in the region of 3,0 kHz.^{37,138} *Voice classification* seems to play a major role in the way the singer adopts a specific laryngeal posture.

According to Winckel,^{63,65} and Sundberg³⁴⁸, formant frequencies, i.e., articulation, are of paramount importance to the voice sounds. They totally determine vowel quality, and they give major contributions to the personal voice timbre. Moreover, they can be used by singers to reduce the timbre differences which result from a shift between registers.

Pershall and Boone²⁴ found that the settings to produce the “**ring**” were quite like those used in the “**cover**”.

Important aspects such as the increasing lip- and jaw openings with increasing fundamental frequency,^{119,128,143} formant tuning,^{35,38-39,77,143} widening of the pharynx and vertical laryngeal height lowering as inducing factors for obtaining a more resonant and far carrying sound,^{5,37,40,43,45,73-74,78,80,99,105,108,118,127-128,138,145-152} even over big orchestras, associated with the well-known problem of intelligibility of high pitches (especially for female voices)¹⁵³⁻¹⁵⁵ are thoroughly studied.

With the aid of modern instrumentation, vocal quality has been dissected in tiny black lines, which can learn a lot to the voice researcher, but, as Miller⁹⁰ proclaims: “Yet no spectral analysis will ever tell all of the facts regarding quality in the singing voice”.

Studies on *jitter* (cycle-to-cycle perturbations in fundamental frequency) and *shimmer* (perturbations in amplitude) and degree of spectral noise (*S/N ratio*) demonstrate the many difficulties in discerning adequately between “normal” and “pathological” voices.^{15,80,86,90,153-170}

Some authors even concluded that “jitter and shimmer measures in extended phonation were not adequate as index for the detection of laryngeal pathology”.^{80,86,163-170}

Pabon and Plomp¹⁷¹ and Pabon^{158,171-173} described a method of automatic phonetogram registration in a silent booth, including acoustic voice quality parameters such as jitter, shimmer, and the crest factor.

In everyday practice, however, both therapist and patient are in desperate need of a more accessible aid to catch the actual quality of a given voice. Efforts were made to objectify the singer’s formant.

Of course, it would be quite interesting to include *a simple indication of voice quality* within the traditional F° SPL measurement.

Seidner et al.,¹⁷⁴ proposed a numerical evaluation of the spectral voice areas, with a strong accent on the importance of the measurement of the *singer's formant* in the phonetogram (“**spektrales Stimmfeld**”). **The absolute intensity value of the singer's formant characterizes the carrying power (“Trag- und Durchdringungsfähigkeit” der Stimme) and the quality of a given voice.**^{37,80,101,106,138,176-179}

According to Schultz-Coulon,¹⁸⁰ the concept of the **carrying power** provides a definite indication for quality and efficiency of the voice.

Titze¹⁸¹ made a study on the acoustic interpretation of *resonant voice*, by most clinicians considered as “*a target vocal production in terms of vocal health*”. *Resonant voice seems to contain the ideal mix of laryngeal adduction (somewhere between breathy and pressed) and ample reinforcement of vocal fold vibration by the vocal tract.* He calls vocal “ring” a by-product, a clustering of higher formant frequencies to raise the spectral content in the 3000 Hz region.

The intensity of the singing formant is dependent on voice intensity, pitch, and *voice classification*.^{99,178,182} The singing formant of basses and baritones is situated between 2,5 and 3,0 kHz, and higher than 3,5 Hz in sopranos.¹⁰¹ Sundberg¹²¹ too, acknowledges that the relation between the centre frequency of the singer's formant is relevant to *voice classification*. He maintains that the centre frequency of the singer's formant varies, *depending on the voice category*, but on slightly different frequencies: in bass singers, it centres around 2,2 kHz; in baritones, around 2,7 Hz; in tenors, around 3,2 Hz.; and in altos, around 2,8 Hz.^{121,125,127}

*These strong partials around 3,0 kHz are clearly decreased in functional voice disorders.*²¹³

Sataloff⁴⁵ acknowledges that the singer's formant significantly contributes to the *difference in timbre among voice categories*, occurring in basses at +/- 2300 Hz, baritones at 2600 Hz, tenors at 2800 Hz, mezzos at 2900 Hz, and sopranos at 3200 Hz. It is frequently absent in high soprano singing.

The improvement of the carrying power of the singing and/or speaking voice is one of the major objectives of voice training and voice.^{2,11-12,101,184-187,}

Because there seems to be no uniform agreement of the definition of the singer's formant, Omori et al.⁸⁰ introduced the ***Singing Power Ratio (SPR)*** - defined as the ratio between the highest intensity peak between 2 and 4 kHz and the highest intensity between 0 and 2 kHz. -, as a quantitative measure of the resonant (ringing) quality of the singing voice.

Voice quality is assumed as the most difficult parameter of the voice to evaluate, and the **ear** is considered to be the best instrument for that purpose by a lot of authors.^{56,68,84,88,108,143,165,167,177,188-198}

According to Debruyne⁴¹⁹, evaluation by the human ear is global, considering the purpose of the voice. *The human ear is also unable to hear the individual singers in a choir.*¹³

Sundberg et al.¹²⁹ do not deny the important role of a good musical ear for a successful singer but also point to the importance of proprioception in the glottal region. To date, computer analysis of the voice provides additional information.

Wedin et al.⁶⁸ suggest combining auditory perception with an objective qualitative as well as quantitative instrumental analysis.

Perceptual evaluation of voice quality proved to be highly subjective^{01,58,68,199} ***and remains controversial because of poor correlation among raters.***^{102,153,191,200}

According to Buekers⁶¹, even speech therapists attach too much value to subjective perception and must learn reporting voice changes in an objective and quantitative way. Moreover, auditive stimuli are rapidly passed away.¹⁹²

According to Wapnick and Ekholm¹⁰², "it is common lore that vocal experts often disagree with each other in their evaluation of vocal performance". In their study on expert consensus in solo voce performance evaluation, they found that intrajudge reliability was much higher than interjudge reliability. Experts thus have difficulty in evaluating vocal quality but appeared to be more reliable for very good performances than they were for average performances.¹⁰²

As Sundberg¹²¹ stated:" the sound of a voice consists of several harmonic partials, i.e., a chord of sine tones of different frequencies. Such sets of tones are generally lumped together by our perceptual system and are heard as units. It is in fact quite difficult for us to hear any of these partials as an autonomous tone, even in cases when a particular partial is much stronger

than all other partials”. When fundamental frequency is high, it is difficult to identify the spectrum peaks caused by the formants.⁴¹

Nevertheless, many evaluating lists have been proposed, e.g. *The Voice Profile*, *The Buffalo Voice Profile*, *The Voice Assessment Sheet*, *The GRBAS Scale*, *The RBH scale*, *The Dysphonia Severity Index*, *The Voice Related Quality of Life-instrument*, and so on.^{2-3,16,84,87-88,186,191,201-204}

Yu et al.²⁰⁵ concluded that “despite extensive research in this domain, there is currently no single widely accepted, standardized technique of objective voice evaluation”.

Perceptual evaluation thus remains a very controversial method. Pabon¹⁵⁸ even finds the use of perceptive scales an impossible choice. Nevertheless, there is a need for a global method of measurement of the vocal quality, reflecting the multidimensional character of the voice.^{8,204}

Other clinicians point out that often determination of *quality of life* is missing in multiparametric clinical research. This brings us to the ***special relationship between Psyche and Voice***. Back in the fifties, Trojan^{187,206} proved the relationship between “Stimme” and “Stimmung”. Other authors^{64,73,79,97,169-189,207-230}, stressed the importance on the voice product of factors such as personality, character, typology, constitution, emotions, genetic aspects and so on.

Mutational voice disorders as a problem of identification are well known in clinical practice.²³⁰

Performance anxiety and its influence on the voice, is another of the many indications for the close relationship between⁴³ the psyche and the vocal instrument.

Listeners, too, seem to have idiosyncratic expectations about the nature of the emotion that is required of the role or in the specific scene performed by the vocalist.⁴³

The psychosomatic aspects of diagnosis and therapy of functional dysphonia are still under study,^{223,231} underlying the need of multidisciplinary research and questioning the concept of functional dysphonia.

In an editorial on the importance of the psychosocial interview in the diagnosis and treatment of “functional” voice disorders, Aronson²³⁵ explains “our allegiance to the word “functional” and our failure to

acknowledge emotional stress as responsible for many of these voice disorders.” Some studies even accept that functional dysphonia usually occurs in people who are emotionally unstable.²³⁶⁻²³⁷

Considering the huge difficulties to adequately describe voice quality, let us simply conclude with the remark of Michel⁷⁹: “*Language is simply inadequate and not up to the task...*”

1.4. Vocal registers

1.4.1. Definitions and descriptions of vocal registers

Anyone who is interested in voice will sooner or later be confronted with the term “register”. Although most people have some idea of what is meant by “register”, an exact definition of register seems to be almost impossible (Seidner)¹⁰¹

Authors like Large²³⁸ and Hollien and.²³⁹ still keep referring to the well-known register definition of Garcia (anno 1840):” *a series of succeeding sounds of equal quality on a scale from low to high, produced by the application of the same mechanical principle, the nature of which differs basically from another series of succeeding sounds of equal quality, produced by another mechanical principle*”, or to the more extended definition of Nadoleczny (anno 1923), who assumed that the internally similar tones of one register were dependent upon a definite, invariable behaviour of the harmonics.

Tarneau¹ emphasized the fact that untrained voices present a disproportion between the laryngeal sound and the resonance in the pharynx of untrained voices, which results in clearly perceptible registers and **passagios**. With a well-established muscular training, these registers and passagios disappear. In other words, the singer has learned to tune his pharynx to the sound produced by the larynx.

Hirano et al.¹⁸ stressed that register, pitch, and intensity are not independent parameters in the human voice. Register is primarily regulated by the vocalis muscle, especially in the chest register. The lateral cricoarytenoid, interarytenoid and cricothyroid muscles also cooperate.

A voice register is usually seen as a *totally* laryngeal event. Spencer and Titze,²⁴⁰ however, nuance this statement and define registration as a

primarily laryngeal event. “Acoustic and myoelastic influences on register transition may exist along a *continuum* of blended interactions.”

A register change means a change in vibrating mode⁵⁵ or an actual change in source function.²⁴⁰

Scientists agree that voice registers must be *operationally* defined: perceptually, acoustically, physiologically, and aerodynamically.²⁴¹ Titze²⁴² even expressed the need to describe registers also on the neuromuscular, biomechanical, and kinematic level!

For obvious reasons some researchers prefer to limit their endeavour to only one aspect of the problem, e.g., the physiological description, admitting that “no single investigation can hope to address all the elements previously cited”.^{18,240}

A complete understanding of the physiology of register function is still lacking.¹²⁴

Voice registers can be seen as voice quality phenomena, but labels, such as falsetto, normal male, etc., could bias the observer’s judgments.²⁴³

To complicate things, some authors²⁴⁴ also consider the “*covering of the voice*” as a kind of register. This mechanism consists of the *forward clapping of the thyroid cartilage and the stretching of the vocal folds*.

Pershall and Boone²⁴ speculate that “to produce a high C from a male larynx would require a very high breath pressure against a maximally tensed vocal fold with supraglottic laryngeal constriction. The larynx is kept in a low position, the epiglottis is erected, the supraglottal space is enlarged, the laryngeal ventricles are expanded, the first formant frequency is lowered, and the second formant frequency is increased.”²⁴⁵⁻²⁴⁸ *This happens on a fixed point, in contrast to the transition from chest register to falsetto register, which can be shifted. This fixed point is situated at c1/d1 for the bass, d1/e1 for the baritone and e1/f1 for the tenor. For female voices (alto – mezzo – soprano) this fixed-point lies one octave higher. The finding of this fixed point is considered as important for voice classification*²⁴⁴

*The purpose of covered singing (mainly used by males), is said to smooth the register transition near the so-called **passagio** (250-400 Hz, depending on voice category).*^{247,249-252}

Vilkman et al.²⁵¹ consider the covering of the voice as a “mixed register in which falsetto and chest register qualities coexist and thus the voice source is richer in harmonics even at high pitches.”

The colour of the voice becomes darker above the passage.^{73,246,249}

The **covered voice** (voix couverte, voix sombrée, gedeckte Stimme, gedeckte Tongebung, voce coperta) is considered the only way to safely sing the highest tones, thus achieving equalization of register.^{37,73,103,246,249, 251,253}

This technique of covering the voice can be applied to the whole vocal range.²⁴⁹

Many singers (mostly untrained) try to continue to sing the tones above the passage in an **open voice** (voix ouverte, voix blanche, offene Stimme, offene Tongebung, voce aperta, chest register) as high as possible.^{73,92,103,252,254-255} The open voice is produced with tensions in the neck and with a high larynx position. With ascending pitch, all vowels sound the same and become reedy. Prolonged open singing provokes **tremolo**.^{37,252}

Untrained voices show a “vocal break”, i.e., “a sudden transition from one voice register to another”.²⁵⁶ The trained male singer, however, changes the position of the first formant (F1) to fall below the second harmonic (H2) in the transition from *chest register* to *head register*.²⁵²

The bridging of chest register to falsetto register (c1 – f1 for male voices and c2 – f2 for female voices) is also called “**voix mixte**”^{243,254,257}.

The controversy is at its highest level when the number of existing voice registers is discussed. The exact number of registers remain unknown but varies between 1 and 107!²⁵⁸⁻²⁵⁹

Schutte and al²⁵⁹ and Miller and Schutte²⁶⁰ cite the historic Italian school, identifying several categories of registration timbres such as: (1) voce di petto (chest voice), (2) voce mixta (mixed voice), (3) voce finta (feigned voice), (4) voce di testa or voce piena in testa (head voice) and (5) falsetto.

The feigned voice and male belt are considered as the mild and strenuous forms of the “register violation. Voix mixte, voce finta and belt are different expressions of the robust “head” register.”²⁷²

Hollien²⁵⁸ postulates that only three major registers exist; they are the **pulse, modal, and loft registers**, but in the literature, we still can find studies on

the so-called *whistle register* (*flute register, flageolet register, Pfeifregister*)^{39,73,202,260,273-274} and the *Strohbasregister* (*pulse, vocal fry*).^{1,239}

To many researchers “*the riddle of the middle register*” still exists,^{113,261-267} while Miller et al.²⁶⁵ proposed the name of *mezza voce* as a distinct register of the male singing voice.

Miller and Schutte²⁶⁶ also discussed the question whether the female middle voice is a combination or balance of the primary registers, chest and falsetto.

Titze²⁴² discerns two types of transitions: a periodicity transition from a continuous tone (chest) to a series of pulses (vocal fry) and a timbre transition corresponding to the primary and secondary passages, based on changes in the closure conditions of the glottis.

Although a vocal register is considered as a “totally laryngeal event”,^{241,268} certain authors feel to make a distinction between singers and nonsingers^{239, 241,263,269}, and between speaking vs. singing registers.²³⁹

The singer seems to have the continued potential to use the voice registers if necessary or desirable.^{362,368,374,380} *So, trained singing voices could (or should?) exhibit only a single register, while retaining their original set of registers.*^{258,263,269} Equalization of registers may be related to the laryngeal mechanism of medial compression.²⁷⁰

Comparing the findings within and between studies remains very difficult, primarily because of the discrepancies in the register systems used.²⁷¹

No one can deny that further research on vocal registers is necessary.

1.4.2. Properties of the registers, based on physiological mechanisms

According to Klingholz et al.,^{279,282} the larynx can't produce all pitches of the voice range with the same mechanism and many adjustments of muscular and aerodynamic forces may occur in phonation.^{18,175,238,249,262,276-279}

Each voice register is characterized by specific properties and dependent on specific physiological mechanisms, which are described in my doctoral thesis¹¹:

- **Pulse register or Vocal Fry.**
- **Chest or Modal register.**
- **Falsetto / Loft register.**
- **Middle register (voix mixte, mezza voce).**
- **Whistle register (flageolet register, Pfeifregister).**

1.4.3. Location of the registers

Although vocal registers are known to occupy separate portions of the total fundamental frequency range of the human voice,²⁷⁶ perceptual judgments alone invariably lead to endless discussions and controversies.²⁶¹ One just must bear in mind the still existing practice of trying to locate registers by means of the subjective sensations felt by singers in some parts of their body.^{239,243,276,282-283}

In addition, the practice of register balance in educated singers interferes with locating the register transitions²⁸⁴ and transitions sometimes lay outside the normal ranges on account of a given voice disorder.²⁸⁵

Nevertheless, McGlone¹⁹ prefers a method of self-determination of the shift between the registers, since that is “more reliable than having judges make the decision”. However, Neumann et al.²⁸⁶ found that “singers themselves are frequently unable to locate their point of transition and to distinguish clearly between registers”, while the judgment by musically trained persons is also questioned. “*Identification of vocal registers is still a formidable task for the investigator-listener*”.

The scientific approach of register location is even more hazardous. The position of the larynx, the waveform of the vocal folds, the aerodynamics of the vocal apparatus, the voice quality and even the subjective feeling of the singer just give a few possible indications, according to Klingholz et al.^{175,282}

The register transitions, visible in the phonetogram, at certain frequencies illustrate clearly the different mechanisms based on pre-phonatory larynx positions and specific muscle activities.

According to Klingholz,¹⁷⁵ 80% tenors, 83% baritones, 71% basses, 86% sopranos, 75% mezzos and 88% altos were correctly identified by his *method of ellipse parameters*. However, he admits he couldn't classify the faulty classified subjects because of their little vocal capabilities...

In a study on mutational voice disorders of young men, Hammarberg²⁸⁷ affirms that the pitch change during normal mutation is often one octave. However, in contrast to most observations, she thinks that “the voice breaks in the full-grown larynx normally occur one octave above the normally used pitch”.

As frequency location could not be the sole characteristic of a vocal register,⁸⁰ I am convinced that more attention should be paid to its *vocal intensity characteristics*. It is here that, in my opinion, phonetography can open a new era of voice research.

Of course, a lot of scientists discovered the often eye casting dip(s) in the phonetogram but interpretation always remained obscure.

According to Klingholz et al²⁸² and Airainer and Klingholz,²⁸⁵ *markers of the register ranges are the transitions which are indicated “by minima in the forte contour and maxima in the piano contour, and minima of the dynamics, at specific pitches.”*

Pabon¹⁵⁸ prefers to talk about *a region where modal and falsetto register overlap*. He acknowledges that, in general, register differences are accentuated by a greater effort (louder voice production, higher pitch). In his earlier publications^{156,173} automatic phonetogram registration is considered to be helpful to determine voice breaks and to indicate register contours, *facilitating voice classification*.

In a following study, however, the same author thinks that the register transition from modal to loft cannot be located with certainty from the phonetogram or by the ear.¹⁵⁸

Glissandos, for instance, cause a larger “dip” and high pitches can be obtained in the modal register by a singing technique, based on forcing. This also means that *the singer has a choice, be it limited to camouflage or to accentuate the register transitions*.

Frank and Donner²⁸⁸ report that register transitions can be shifted in pitch when someone is singing for a long time in a faulty voice classification. Moreover, a tenor, for instance, can perform a register equalization like a baritone and older voices can show shifts in register transitions.

A lot of authors regard *the dent in the phonetogram of untrained normal voices as a mark for the transition from chest-voice to falsetto voice. A well-trained voice no longer shows any such dip*,²⁸⁹ or “the condition is