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Maximum Phonation Time, s/z and a/z ratio: reference values for Speech-Language Pathologists

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Abstract: The maximum phonation time (MPT) is a common test for assessing phonation as part of speech therapy evaluation. It is relevant in numerous pathologies including dysphonia and dysarthria. The protocols for conducting this test differ according to the field of application and the country. The phonation time analysis tool implemented in the VOCALAB software helps to standardize this test. In this article, we review the data available on the maximum phonation time, the s/z and a/z ratios, from which we extract global trends according to age and gender. We then propose reference values which situate a patient's performance in relation to normal, altered, or pathological phonation time. The alteration of phonation duration and s/z ratio is also studied for a selection of voice pathologies. Through one case study, we illustrate the evolution of performances before and after speech therapy.

Keywords: Maximum Phonation Time, MPT, s/z ratio, a/z ratio, voice pathologies, dysphonia, nodules, speech therapy, VOCALAB

Introduction

The test which consists in asking a patient to pronounce a sustained vowel “as long as possible” is very common in phonation assessments such as those described in [Dejonckere 2011], [Ghio 2007], [Menin-Sicard 2013], [Mornet 2014] or [Laganaro 2021]. This test is called “Maximum Phonation Time” (MPT). The most common vowel is /a:/ because of its universal nature. The vowel /a/ is considered as extreme because of the maximum opening of the mouth and low position of the jaw. The patient should take a full inspiration, and, at a spontaneous pitch and comfortable volume, prolong the vowel for as long as possible. The extraction of the maximum phonatory time is generally based on three trials as recommended in [Dejonckere 2011] and in the VOCALAB assessment protocol of [Menin-Sicard 2013].

This measurement is widely used in speech therapy clinics for practical reasons: it is a non-invasive approach, quick and easy to implement, allowing to evaluate speech performance. All is need is a stopwatch or a computer tool to record the voice and extract the speaking duration for the portion where the energy exceeds a certain threshold. This measure is considered relatively reliable, as reported by [Speyer 2010], but the values published in the literature are quite variable, due to non-standardized protocols. This lack of consensus is also quite recurrent in the field of objective voice measurement because there are no methodological guidelines concerning the equipment, the recording protocol, and the most relevant choice of analysis algorithms, which makes it difficult to compare results between different studies or the values produced by different analysis software.

The MPT is one of the four parameters included in the formula for the Dysphonia Severity Index (DSI) defined by [Wuyts 2000], and is considered one of the parameters best correlated with the degree of

severity of dysphonia according to the study by [Yu 2001], as well as the severity of dysarthria, according to [Rusz 2015].

One of the oldest compilations on MPT was published by [Kent 1987], which listed in a table numerous maximum phonation time values of /a:/ as a function of age and gender. A more complete review was conducted by [Baken 2000] some years later, covering more than 20 scientific references. More recent studies have focused on the MPT for elderly voices [Malsan 2011] or the voice of children [Tavares 2012]. However, we were unable to identify an updated meta-analysis allowing us to extract a clear trend according to age, as well as the threshold values below which phonation time can be considered impaired or pathological. This is one of the objectives of this research report.

The use of the s/z ratio as an indicator of severity of laryngeal pathology was initially studied by [Ekcel 1981]. Different values depending on age were also listed in [Kent 1987] in connection with this metric, complementary to the MPT. Similarly, the work of [Baken 2000] lists some values of s/z ratios published on the one hand on normal voices, on the other hand on pathological voices. Numerous studies followed, addressing pathologies such as nodules [Rastatter 1982], stuttering [Salihovic 2009], dysphonia [De Olivera Lemos 2017], asthma [Dogan 2007] or multiple sclerosis [Dogan 2007b]. Finally, the a/z ratio is much less described with in the literature [Gilman 2021], although integrated into the assessment protocol of the VOCALAB tool [Menin-Sicard 2013].

In this article, we compile the open data available on the MPT, s/z and a/z ratio, and present the raw values in the form of a summary graph, to extract global trends. The curves are outlined according to age and gender, from which we propose reference values to separate normal, altered, and pathological voice. The impact of a selection of pathologies on MPT and s/z ratio is also reviewed. Some case studies outline the evolution of these parameters before and after speech therapy.

This paper is the translation in English of the review published in French on hal.science in 2021¹.

Summary of available data on phonation time

We have identified more than 60 data sets linked to maximum phonation time based on 35 different bibliographic references. We focus mostly on publications in open archives, including some such as [Kent 1987] which provided a review of the literature available on the subject nearly 35 years ago. Each MPT value is placed on a graph as a function of the age. We distinguish the curves for men (Figure 1) and women (Figure 2). In these figures, despite huge variations in the number N of patients (from 5 to 200 individuals per age group, depending on the study), we give the same importance to each average value, which is represented by a point. We have reported in Appendices A and B the numerical values of MPT, supplemented with the number of people and the standard deviation if available.

¹ Etienne Sicard, Anne Menin-Sicard. Temps phonatoire, rapport s/z et a/z : repères en lien avec la prise en charge orthophonique. 2022. [hal-03662213](https://hal.science/hal-03662213)

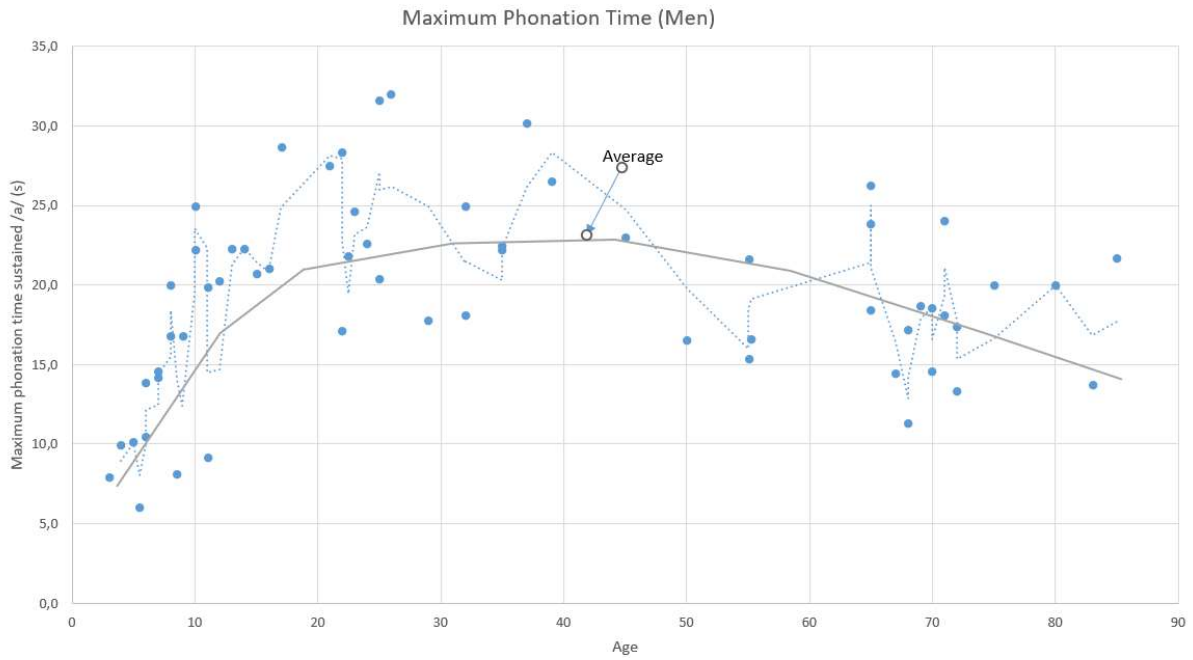


Figure 1: MPT for men according to 50 average values extracted from scientific publications, total 1950 men (Healthy control)

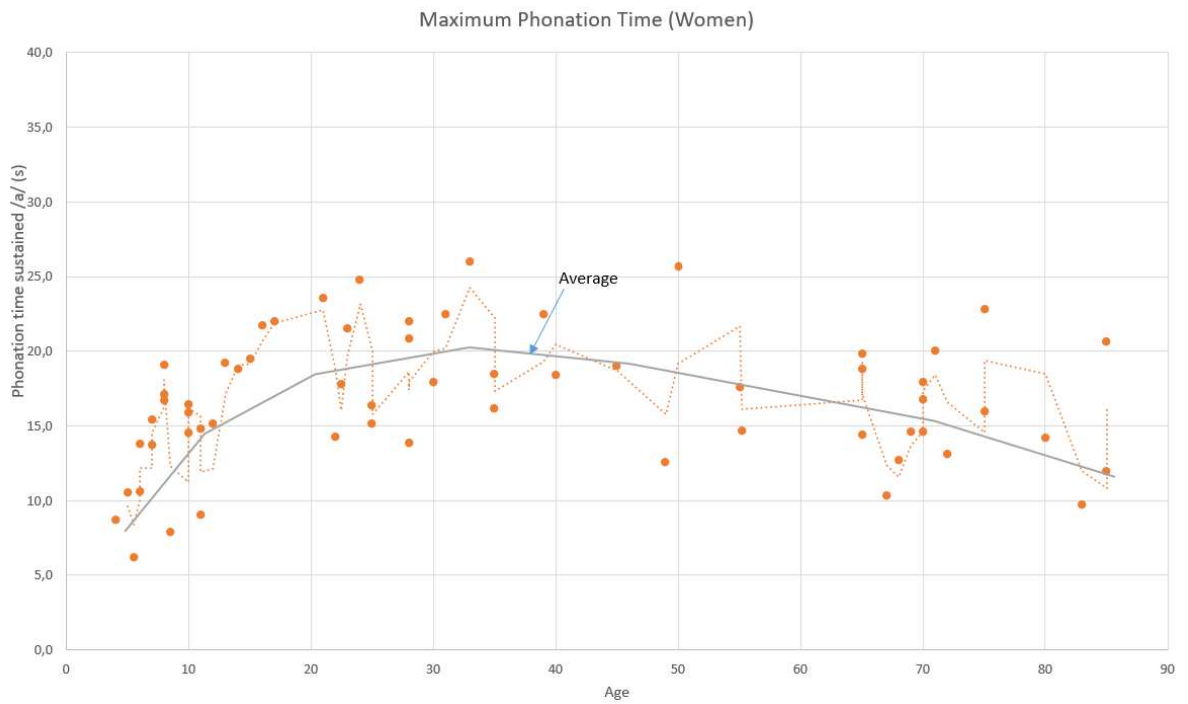


Figure 2: MPT for women according to 50 average values extracted from scientific publications, total 2100 women (Healthy control)

We also add a moving average in dotted lines, and a smoothed average in gray, as illustrated in Figures 1 & 2. The differences between the results of the studies, for a given age, are significant. It is possible to distinguish an upper curve, a lower curve, and many points in between these extreme trends. We can also note in Figure 1 an increasing trend up to age 30, with a MPT which reaches 25 seconds, then a slight downward trend with age. Concerning women, the shape of the curve is similar (figure 2), the MPT rising to 20 seconds on average between 20 and 50 years old, that is 5 seconds less than men. The average difference between men's and women's MPT is approximately 4 seconds.

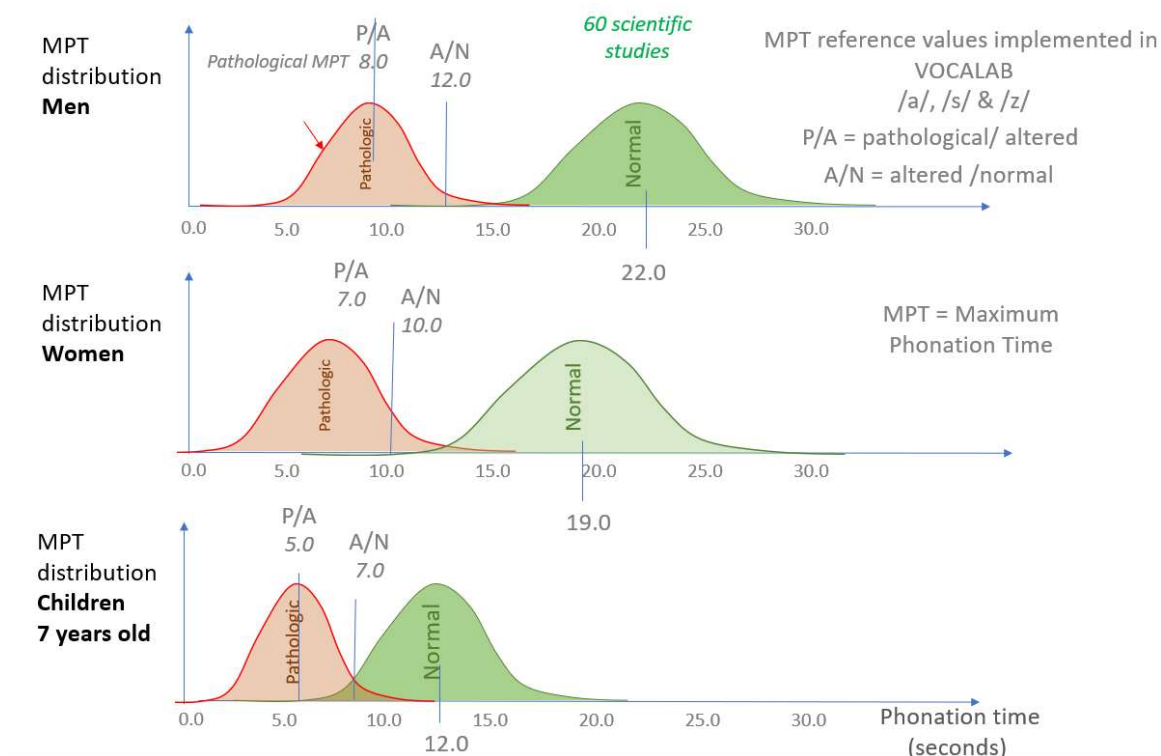


Figure 3: MPT distribution for the normal group and the pathological group according to a Gaussian-type distribution based on standard deviation, for men, women, and children.

The MPT's standard deviation for the age group 15-65 years is 7 seconds for men and 6 seconds for women, extracted by computing the average of the standard deviations published in the different bibliographic resources, whether weighted or not by the number of patients analyzed (Appendices A and B). We consider the normal law (Gaussian-shaped curve, see figure 3) as an acceptable model of the statistical distribution of MPT values corresponding to normal phonation. We can define (table 1):

- A first threshold value at 1 standard deviation σ below the mean. About 84% of normal people can reach a MPT above this threshold. This threshold is approximately 13 seconds for women and 15 seconds for men.
- A second threshold value at 2 σ below the mean. About 98% of normal people can achieve a MPT above this threshold. This threshold is approximately 7 seconds for women and 8 seconds for men.

Age range	Gender	N-dependent	Average MPT (s)	Std Dev (σ , s)	MPT $-\sigma$ (s)	MPT -2σ (s)
15-65	Women	No	19,4	6,0	13,4	7,5
	Men	No	23,1	7,2	16,0	8,8
	Women	Yes	18,6	6,0	12,6	6,5
	Men	Yes	22,2	7,3	14,9	7,6

Table 1: MPT reference values according to the 60 published values extracted from the scientific literature reported in Appendices A (men) and B (women), without taking into account the number N of controls in the study (lines 1 & 2) or depending on N (lines 3 and 4)

Changing the averaging method (geometric instead of arithmetic) only marginally changes the threshold values (between +/- 0.1 and 0.4 seconds). Considering the number N of patients in the form of a weighted average, on the other hand, gives considerable importance to a small number of studies such as [Tavares 2012] with 1660 children or [Laganaro 2021] with 202 women and 187 men.

The main issue of the study by [Tavares 2012] is that the published values are significantly below all the others at a comparable age. Favoring a particular protocol which seems outside the main trend seems dangerous and could bias the entire study.

A reasonable approach consists in applying a logarithmic weight (3rd and 4th rows of Table 1) to limit the effect of N while integrating a weighting effect to highlight studies with large cohorts. In that case, the MPT and the associated thresholds decrease by approximately 1.0 seconds, while the standard deviation remains approximately the same. We will use these thresholds as reference values for our software tool VOCALAB [Sicard 2021].

Protocol

The MPT results can be significantly different depending on the number of trials (from 1 to 10 depending on the authors), and depending on the algorithm used (the maximum or the average). We list different approaches found in the scientific literature by reporting the number of trials, the calculation approach, the production of a model, and the duration of pauses between trials (Table 2).

PUBLICATION	TRIALS	ALGORITHM	PRODUCTION OF A MODEL	PAUSE
[SHANKS 1977]	10	Max	Yes	60 seconds
[JOHNSON 2015]	3	Max	Yes	60 seconds
[LAGANARO 2021]	Unconstrained	Max of trials		
[TAVARES 2012]	3	Max	Yes	
[KNUIJT 2017]	1		No	
[MASLAN 2011]	3	Max	Yes	60 seconds
[MENIN-SICARD 2016]	3	Average	No	No pause
[CUNHA 2019]	3	Average		Free
[VACA 2017]	3	Max		
[GILMAIN 2021]	1		Yes	
[VIRMANI 2016]	3	Average	No	

Table 2: Number of trials, type of algorithm, protocol options such as production of a model of pauses between phonem productions, according to a selection of publications

The heterogeneity of approaches can be one of the possible explanations for the diversity of measurements observed in Figures 1 and 2, and the presence of “upper” curves and “lower” curves. Calculating the average will generally give results 5 to 10% lower than looking for a maximum over several trials, with a long pause. Concerning the latter, the duration of pause between the productions of sustained vowels is quite variable: the time of a spontaneous inspiration [Menin-Sicard 2016] up to a minute of recovery [Maslan 2011].

The impact of other variations in the protocol have been studied, such as [Cunha 2019] which does not observe a significant difference between the MPT obtained sitting or standing. The values of the second tests are always slightly higher than for the first (around 5%).

Some reasons for observing high MPT are mentioned by [Malsan 2011]: stricter inclusion and exclusion criteria, inclusion of sound portions with very weak amplitude at the end of phonation, duration of pause, coaching between trials, variations in the instructions, training effect in the case of multiple trials.

The 3-trial approach

The advantage of measuring 3 successive values of the maximum phonation time is to analyze the evolution of phonation durations, which can, in addition to evaluating the average value, provide additional information to the SLP:

- If MPT performance improves during the tests, this means that the patient is implementing a relevant adaptation to the situation. The possibility of a learning effect is therefore seen here as a positive indicator and not a bias to be avoided as in [Gilman 2021];
- If the values are the same during the 3 trials, this means that the patient does not spontaneously seek adaptations to improve or does not have the phonatory abilities to do so;
- If the values during the 3 tests deteriorate, this highlights fatigability. Inspiratory recovery may be ineffective between trials.

Thresholds implemented in VOCALAB

The thresholds for normal/impaired phonatory time may be based on the mean values minus one standard deviation (which includes 85% of normal MPT). Accordingly, the threshold for impaired/pathological phonatory time may be fixed to -2 standard deviation (98% of normal MPT). In our implementation of MPT in VOCALAB, we set thresholds a little lower than weighted averages defined in Table 1 for the following reasons:

- The “Maximum Phonation Time” protocol as designed in VOCALAB is an effort test to the extent that the protocol does not include recovery time in the 3 required trials of sustained /a:/, /s:/ and /z/, i.e. 9 phonations trials. Several protocols in the meta-analysis include a recovery time between each trial of one minute, as studied in Table 2, which is not the case here. The threshold must therefore be revised slightly downwards;
- The calculation of the indicators is not based on the maximum of the 3 values, but on the average of the 3 values. We indeed consider that the progression or regression of values is an interesting indicator of the patient's abilities. The threshold must therefore once again be revised slightly downwards;
- We do not make the patient listen to an auditory model with normal MPT nor provide an example, with the goal to encourage the patient to get as close as possible to maximum phonation performances. Some authors such as [Soman 1994] have shown that providing a model allowed certain patients to prolong phonation a little longer.

The Normal/Impaired and Altered/Pathological thresholds used by VOCALAB [Sicard 2022] are listed in Table 3. For children, the MPT is proportional to age and reaches the adult curve at 15 years old. For the elderly, beyond the age of 65, we consider a slope of decrease in reference MPT of around -2 seconds every 15 years, following the trends observed in Figures 1 and 2. Thus, at age 80, the normal/impaired limit for MPT is lowered to 10 seconds for a man, and to 8 seconds for a woman.

<i>Age</i>	<i>Gender</i>	<i>Threshold Normal/Altered (s)</i>	<i>Altered/Pathological Threshold(s)</i>
<i>Children 6-8</i>	<i>Children</i>	<i>6</i>	<i>4</i>
<i>Adult 15-65</i>	<i>Women</i>	<i>10</i>	<i>7</i>
	<i>Men</i>	<i>12</i>	<i>8</i>

Table 3: Normal/Impaired MPT thresholds implemented in VOCALAB 4.5 [Sicard 2022]

Normalization

The reference thresholds depend on gender and age. The advantage of giving, in addition to absolute values, a standardized indication of the MPT performance allows to present the results in the same way: the higher the performance, the lower the alteration indicator, the greener the associated color will be. The threshold limit is 1.0, regardless of age and sex. We specify in table 4 the color code implemented in VOCALAB.

The example in Figure 4 corresponds to case study AS033 [Menin-Sicard 2021], a 64-year-old woman with damage to the superior laryngeal nerve, associated with desynchronization of the vocal folds. Laryngeal examination revealed limited adjoining surface area, air loss, and asymmetric vocal fold function. Before therapy:

- The sustained /a:/ is pronounced for an average of 4.7 seconds, significantly below the standard of 10 seconds for a woman,
- The sustained /s:/ is also a bit short: 8.4 seconds,
- The sustained /z:/ is very short: 3.5 seconds.

There is a tendency to reduce phonation times along the 9 trials. Most indicators are outside normality zones.

<i>Pathology indicator</i>	<i>Colour</i>	<i>Meaning</i>
<i><0.8</i>	<i>Green</i>	<i>MPT above the Normal/Impaired threshold</i>
<i>0.9-1.3</i>	<i>Orange</i>	<i>MPT slightly below the Normal/Impaired threshold</i>
<i>> 1,4</i>	<i>Red</i>	<i>MPT below the threshold Impaired/Pathological</i>

Table 4: Meaning of the pathology index values of the Phonatory Time module

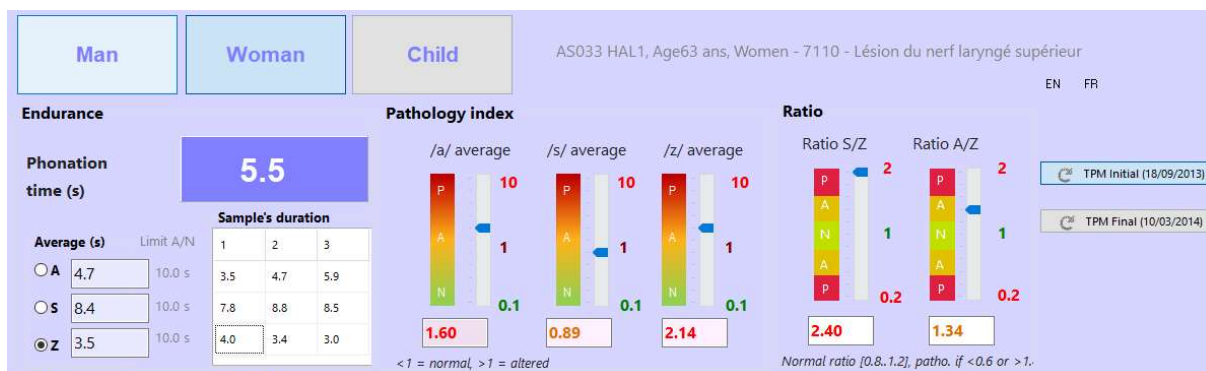


Figure 4: Phonation time for 3 trials, average of the 3 trials for /a:/, /s:/ and /z:/, with corresponding alteration indicators, case study AS033 [Menin-Sicard 2021]

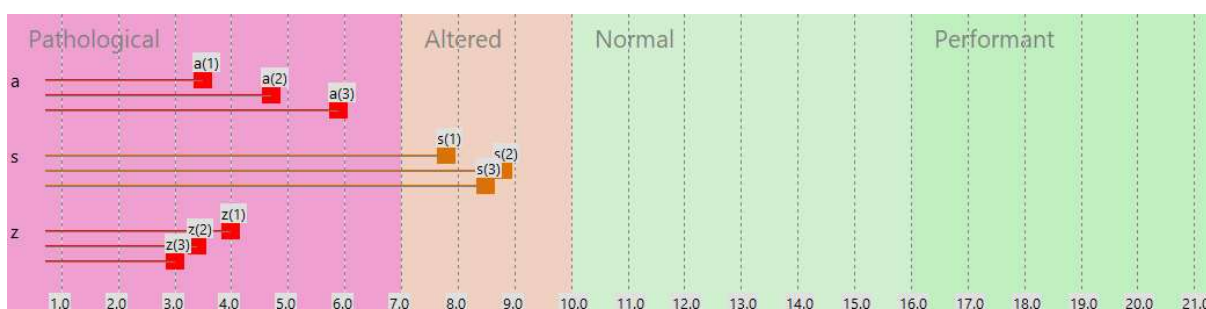


Figure 5: Definition of pathological, altered, and normal values for the Maximum Phonation Time (MPT) in VOCALAB, case study AS033 [Menin-Sicard 2021]

PATHOLOGY	REFERENCE	AGE	N	MPT CONTROL	MPT PATIENTS	MPT RELEVANCE
COVID	[Asiaee 2020]	16-77	64	M: 14,7 W: 13,5	M: 7,02 W: 6,2	***
PNEUMOPATHY	[De Aguiar Cassiani 2013]	56-77	16	18	10,5	***
ASTHMA	[Shrestha 2019]	25-60	20	14,4	7,2	***
STROKE	[Ghoreyshi 2021]	45-80	100		6,7	***
GALACTOSEMIA	[Potter 2011]	4-16	33	12,3	6	***
DYSARTHRIA	[De Cock 2021]	42-97	151		9	**
STROK						
TUBERCULOSIS	[Shrestha 2019]	25-60	20	14,4	11,3	**
DYSPHONIA	[Niebudek 2008]	23-60	133	16,6	13,3	**
PARKINSON	[Fang 2014]	55-75	16	11,3	7,3	**
MUSCLE TENSION	[De Oliveira Lemos 2017]	47-67	30	10,8	8,15	**
DYSPHONIA						
MULTIPLE SCLEROSIS	[Dogan 2006]	21-56	27	23,4	15,6	**
EARLY ENT	[Dagli 1997]	43-86	16	M: 18,6	M: 17	
CANCER		57-87	4	W: 16,8	W: 15	
STUTTERING	[Salihovic 2009]	7-10	34	11,2	10	

Table 5: Relevance of the Maximum Phonation Time (MPT) measurement by comparing healthy control (HC) and patients with various diseases. Relevance is generally assessed on the basis of the p-value ($p \leq 0.05$: * ; $p \leq 0.01$: ** , $p \leq 0.001$: ***)

In the *Phonation Time* module of VOCALAB, we define four distinct color zones (figure 5): the red zone corresponds to a pathological MPT, an orange zone corresponds to an altered MPT, the green zone to a normal MPT, and the rightmost area, in darker green, corresponds to a high-performance duration. The thresholds used are those in table 3. In the example presented, the duration of the 3 trials /a:/ and /z:/ are in the pathological zone, the /s:/ being in the altered zone. Each horizontal bar represents a trial, which makes it possible to judge immediately the different performances during the tests. Here, the picture is clearly pathological.

Relevance of the Maximum Phonation Time

Different studies compared control groups and patient groups in terms of maximum phonation time and for various pathologies. The degree of relevance of the MPT is generally quite high, as demonstrated in table 5. Only two studies do not show a significant differentiation between controls and controls: the patients studied in [Dagli 1997] had undergone treatment for head and neck cancer in average 3 years before the date of analysis and had regained almost normal vocal performance. In the study by [Salihovic 2009], children with moderate or severe stuttering did not have impaired speaking time.

s/z ratio

People with normal phonation generally produce sustained /s:/ and /z:/ of comparable duration, which gives an s/z duration ratio close to 1.0. The idea of calculating the s/z ratio has been initially proposed by [Eckel & Boone 1981] to try to highlight possible problems linked to breathing coordination, constriction, and phonation, which may result in an s/z ratio significantly different from 1.0. The range considered normal is 0.8-1.2 [Tavares 2012] [Menin-Sicard 2016] [De Oliveira Lemos 2017].

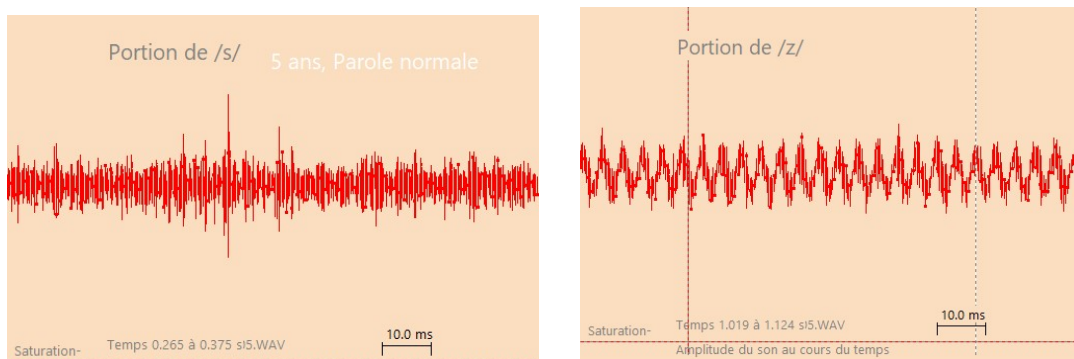


Figure 6: Time domain aspect of sustained /s:/ (left) and sustained /z:/ (right), 5-year-old child, healthy control

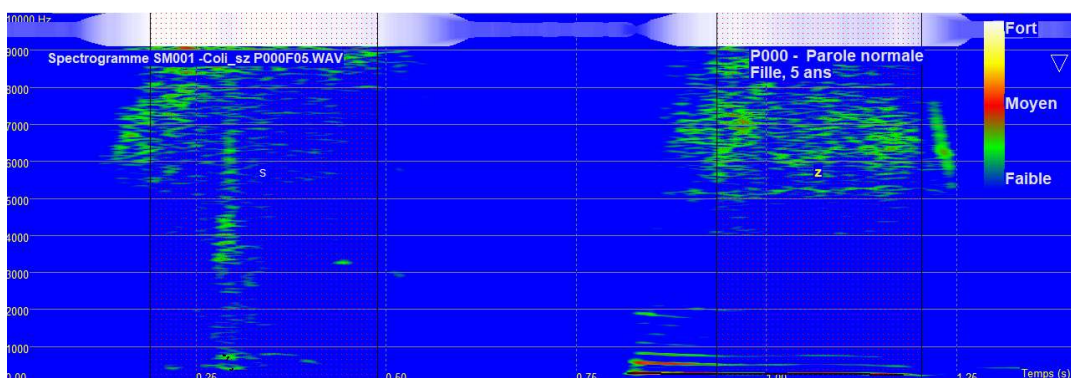


Figure 7: Spectrogram of /s:/ (left) followed by /z:/, 5 year old child, healthy control

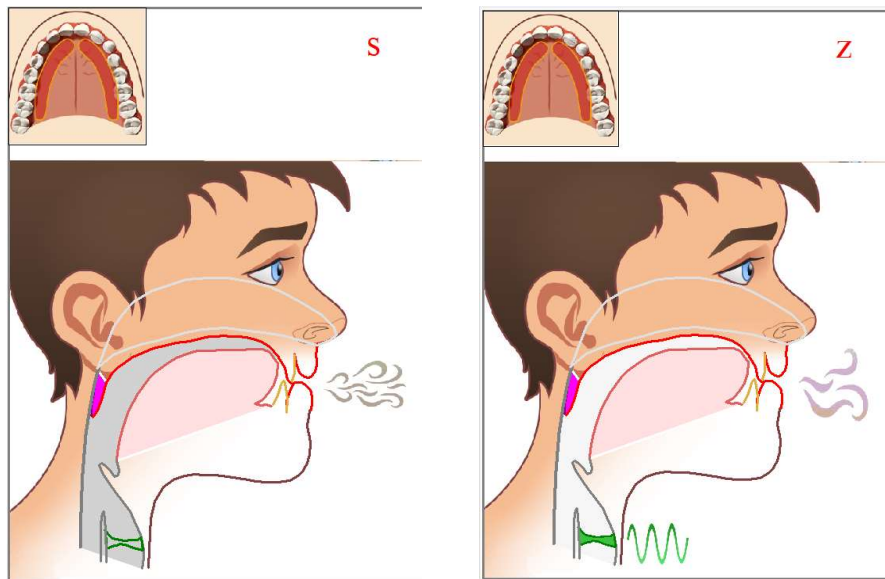


Figure 8: Position of the articulators for /s:/ and /z:/ [Menin-Sicard 2019]

The characteristic signature of /s:/ and /z:/ is the turbulent flow which results in high frequency noise, mainly between 5 and 10 KHz, as shown in the time-domain waveform of Figure 6 and the corresponding spectrogram (Figure 7). The difference between the phonemes /s:/ and /z:/ is the voicing, absent for /s:/ (voiceless constrictive) and present for /z:/ (voiced constrictive), while the position of articulators is nearly identical (figure 8).

Protocol

The use of the s/z ratio in the clinical assessment of phonation has been the subject of much debate in the scientific community as there is relatively little evidence of its accuracy and reliability, in part linked to variability in protocols and different data exploitation approaches. To our knowledge, no standard approach and consensus agreement have been developed to date in relation to this type of analysis.

The fact of giving or not an auditory model has, for example, a significant importance on the duration of /s:/, /z:/, but also of the s/z ratio, as highlighted in [Soman 1994]. In this study, the provision of a model results in significantly higher s/z ratios (1.2) than in the absence of a model (0.9), in a test involving 80 women with an average age of 24 years. Certain protocols such as described in [Gelfer 2006] are based on an analysis of sound pressure at least equal to 60 dB, which corresponds to conversational voice. This author also notes that the durations of /s:/ tend to increase with the number of trials, with /z:/ remaining rather constant.

From his side, [Johnson 2016] notes, for a group of 10 young adults (22 years old on average) and 10 older adults (65 years old on average) a trend towards an increase of 10% in the duration of phonation on the 2nd test, the 3rd returning to the values observed in the 1st test.

Influence of gender and age

The results of [Tait 1980] and [Alves 2015] indicate that there were no significant differences in the values of MPT concerning /s/ and /z/ between boys and girls, and therefore no significant differences in the s/z ratios according to gender, nor significant differences according to age [Tavares 2012]. Similarly, [Gelfer2006] shows, in a study regrouping 20 young men and 20 young women, that the phonation durations of /s/ and /z/ are similar, while the s/z ratios remain close to 1.0, although with notable variability. The studies of [Cunha 2019][Joshi 2020] also show s/z ratios close to 1.0, with no gender impact.

Concerning the elderly people studied by [Pessin 2017], the alteration or atrophy of the vocal folds is quite common, which results in a reduction in the duration performance of /a/, /s/ and /z/ with age, a clear phenomenon already highlighted in Figures 1 and 2, but without significant modification of the s/z ratio.

Summary of data available on s/z

By compiling different sources on the value of the s/z ratio for men and women, we note, contrary to the MPT values, a relative constancy of the figures, whether for children, adults, and elderly people. The average value for all ages is around 0.95 for both men (figure 9) and women (figure 10). We note a remarkable similarity of values between men and women, which contrasts with the discrepancy observed in the MPT evolution curves. Therefore, in VOCALAB we consider the value 1.0 to be the norm for all ages and genders.

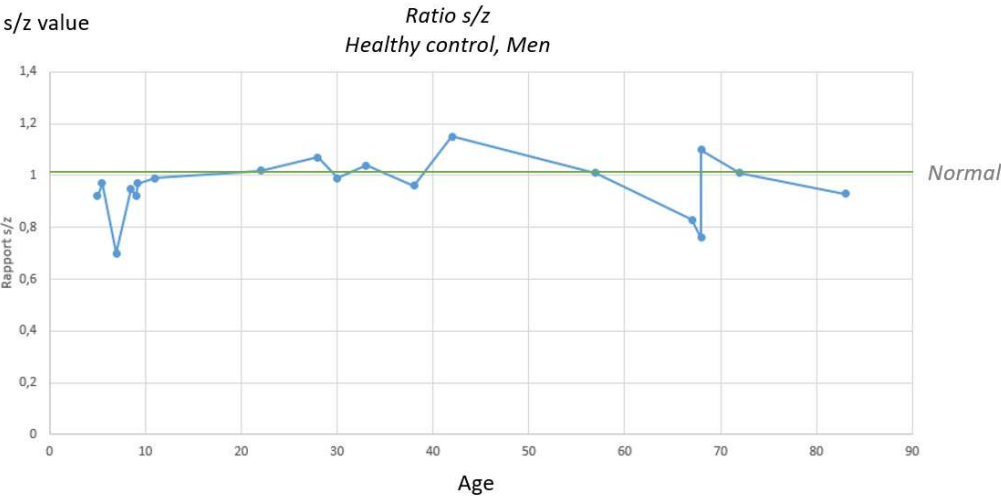


Figure 9: Values of s/z ratios published in the scientific literature for men (Healthy Control) according to age.



Figure 10: Values of s/z ratios published in the scientific literature for women (Healthy control) according to age.

We have reported in Appendices C and D the details of the 20 men's values and 20 women's values published in the scientific literature, the number N of people involved in each study, which made it possible to establish these curves.

Relevance of the s/z ratio

We have brought together in table 6 different results linked to vocal pathologies and the observed values of the s/z ratio. Even if in most of these studies there is no matched control group, we have seen that the value of 1.0 could reasonably be considered as a reference value for healthy controls.

A duration of /s/ greater than that of /z/, therefore an s/z ratio greater than 1.0, may indicate a problem with vocal fold alignment or an air leak caused by laryngeal pathology [Roginski 2020] or a constriction problem. We find in the literature particularly high s/z ratios in [Eckel 1981], for 28 dysphonic subjects with laryngeal pathology, in [Ocal 2020] for 47 patients with vocal cord polyps, or even for 12 young adults with hypo- hydration [van Wyk 2017].

PATHOLOGY	REFERENCE	AGE	N	S/Z	RELEVANCE OF S/Z RATIO
POLYPS	[Ocal 2020]	21-66	47	1,56	***
POLYPS, NODULES	[Watts 2014]	22-74	8	1,47	***
GLOTTIC LEAK	[Vaca 2017]	65-93	104	1,3	***
NODULES, POLYPS	[Eckel 1981]		28	1,4	***
PNEUMOPATHY	[De Aguiar Cassiani 2013]	56-77	16	1,3	***
NODULES, POLYPS, CYSTS	[Virmani 2016]	20-62	30	1,37	**
DYSPHONIA AND NODULES	[Dohar 2019]	1-13	79	1,37	**
NODULES, VF PARALYSIS, EDEMA	[Thomas 2021]		524	1,2	**
HYPO HYDRATATION	[van Wyk 2017]	18-32	12	1,33	**
ASTHMA	[Asnaashari 2012]	20-72	34	1,13	*
DYSPHONIA	[Eckel 1981]		36	1,0	
STUTTERING	[Salihovic 2009]	7-10	34	0,92	

Table 6: s/z ratio values for various pathologies. Relevance is generally assessed based on the p-value ($p \leq 0.05$: *; $p \leq 0.01$: **, $p \leq 0.001$: ***) compared to the average and standard deviation of the s/z ratio evaluated on a control group, or between pre and post intervention.

The threshold $s/z > 1.3$ is considered by [Vaca 2017] as a specific marker of glottal leak. On more than 500 cases of vocal pathologies analyzed by [Thomas 2021], the s/z ratio amounts to 1.2. On the other hand, certain mild dysphonia, or pathologies such as stuttering do not show an impact on the s/z ratio. It can be noted that Table 6 only lists s/z ratios significantly greater than 1.0, and none significantly less than 1.0.

a/z ratio

The /a/ is an open vowel which provides no resistance to the air flow, compared to /z/ which, thanks to the semi-occlusion and the turbulent regime of the constriction made possible by the position of the tongue close to the teeth, facilitates phonatory efficiency (Figure 11). The idea of calculating the a/z ratio in addition to the s/z ratio was put forward by [Menin-Sicard 2013] and implemented in the VOCALAB assessment tool. Unlike the s/z ratio, there is very little scientific literature on the a/z ratio, except for a recent publication by [Gilman 2021]. Table 7 summarizes the expected thresholds for men, women, and children for speaking times and associated ratios.

Phoneme	Description	Threshold Normal/Altered	Threshold altered/Pathological
/a/	Most open phoneme. Does not offer any articulatory support point. Spontaneous and universal. Very little impedance	Women: 10 s Men: 12 s Children: 6 s	W: 7 s M: 8 s C: 4 s
/s/	Unvoiced constrictive phoneme, reduced air flow with very high frequency components without laryngeal vibration. Stretched lip position..	Identical	
/z/	Voiced constrictive phoneme with low and very high frequency components. Part of the air is absorbed by laryngeal vibration.	Identical	
s/z ratio	Evaluate the impact of construction on phonation as a whole	<0.8 or >1.2	<0.6 or >1.4
a/z ratio	Evaluates the impact of phonation on speaking as a whole	<0.8 or >1.2	<0.6 or >1.4

Table 7: Maximum Phonatory Time /a/, /s/, /z/, s/z and a/z ratios with associated limits

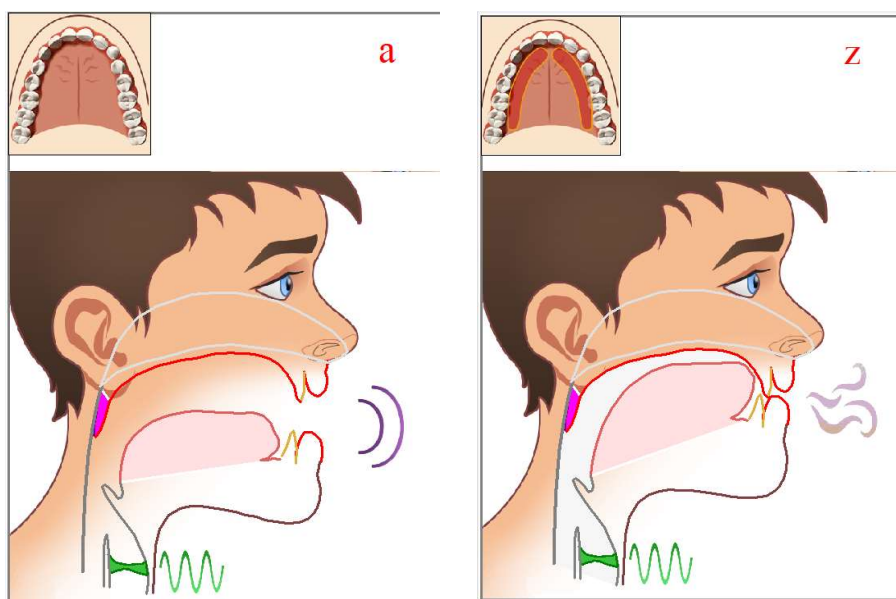


Figure 11: Position of the articulators for /a/ and /z/ [Menin-Sicard 2019]

The study by [Siqueira 2020] on the elderly shows, on 56 healthy seniors aged between 60 and 86, a certain tendency towards a reduction in phonation time on /s/ and /z/, while that the MPT of /a/ remained high. In other words, the s/z ratio was close to 1.0, but the a/z ratio would be slightly greater than 1 (1.1).

Relevance of a/z ratio

The relationship between the duration of the open vowel /a/ and the voiced constrictive /z/ allows us to analyze and understand the influence of articulation on phonation. At an identical articulator position (Figure 11), we seek to know whether the phonation is effective with constriction.

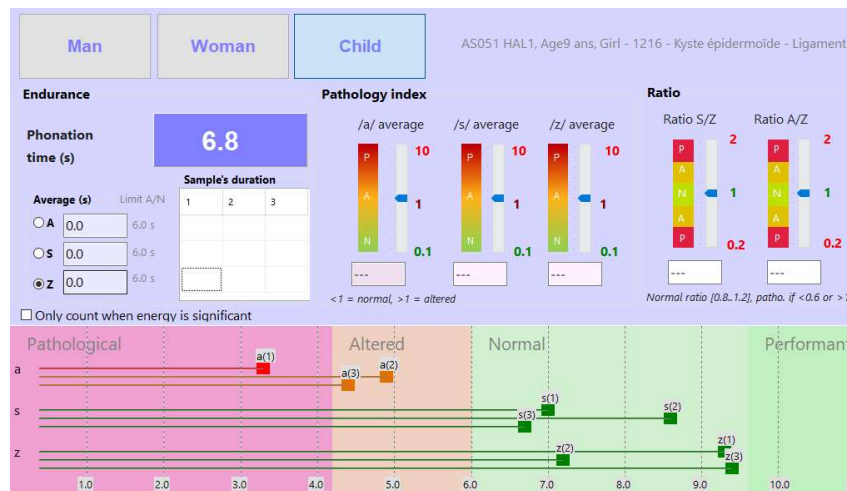


Figure 12: Maximum Phonation time after therapy, case study AS051 9-year-old girl [Menin-Sicard 2021]

If the constriction is efficient and there are no velar insufficiencies, the /z/ should last just as long as the /s/. The s/z ratio therefore allows us to know whether the patient can coordinate constriction and voicing, and whether he can maintain it over time. This measurement is therefore very relevant in the context of multiple pathologies such as dysarthria, articulation disorder, verbal dyspraxia or even apraxia of speech.

There are pathologies for which the MPT of /s/ and /z/ are similar and conform to the norm, with an s/z ratio close to 1, but the MPT of /a/ is much shorter. For case AS051 [Menin-Sicard 2021] illustrated in Figure 12, the MPT values correspond to a 9-year-old girl, having a congenital intra-cordal cyst with reaction nodules. The values correspond to the situation after 3 months of speech therapy treatment. We note values of MPT /s/ and /z/ that are quite close, within the norm for age, i.e. an s/z ratio close to 1.0, but an MPT of /a/ below the norm, with a ratio a/z considered pathological. The quality of constriction has improved during the sessions, but as the cyst had not disappeared. Consequently, the duration of phonation on /a/ remained impaired after 10 rehabilitation sessions. Velar strength was not in question since the harmonic poverty indicator is considered as normal, but the persistence of glottal inefficiency is thus highlighted.

In the case where the /z/ is greater than /s/, a situation encountered in the case of dysarthria or an articulation disorder, there are two causes linked to the articulators. Either the constriction created by the movement of the tongue against the palate and the median canal ensuring the flow of air is ineffective (lingual hypotonia, inappropriate configuration or position of the tongue), or the nasal seal is not or not very confident and it is the action of the velum which is in question.

The phonation time test on 3 phonemes is the only phonation assessment test allowing indirect measurement of supraglottic pressure, a measurement very rarely specified in phoniatic reports. This

supraglottic pressure is however fundamental to stabilize and relieve the glottic plane. This regulation of the pressurization of the vocal track is closely dependent on velar functioning and lingual functioning.

The opposite situation in case AS051 concerning the durations of /a/, /s/ and /z/ is also cited by [Gilman 2021]: the /a/ is sustained for 28 seconds in a 45-year-old man, i.e. a normal MPT, but the durations of /s/ (12 seconds) and /z/ (14 seconds) are significantly shorter, close to the normal/impaired threshold, which gives a normal s/z ratio and a pathological a/z ratio.

GROUP	MPT	S/Z	A/Z
NORMAL	The durations of /a/, /s/ and /z/ are comparable and close to the norm	1.0	1.0
FRICATIVE	Comparable durations of fricative sounds /s/ and /z/, close to the norm, compared to /a/, which is generally shorter	1.0	<<1.0
VOICING	/z/ and /a/ durations are shorter than the norm, and close in duration compared to /s/, which is generally longer.	>>1.0	1.0
MIXED	The durations of /s/ and /a/ are similar, /z/ is significantly longer or shorter.	≠1	≠1

Table 8: Type of pathology and influence on s/z and a/z ratios according to [Gilman 2021]

In [Gilman 2021], 4 groups are distinguished, as described in Table 8: normal, fricative, voicing or mixed group. The s/z ratio is therefore a measure of constrictive-phonatory efficiency, the /s/ being a measure of pneumo-constrictive efficiency, the /z/ being a measure of phonatory efficiency.

The a/z ratio is just as interesting clinically as the s/z ratio, and it is surprising that this measurement remains little known. Indeed, comparing /a/ and /z/ makes it possible to measure a crucial parameter which is velar tonicity. By producing a sustained /a/, the soft palate is the only articulator ensuring the impedance brought back to the larynx, the tongue playing no role here. For the phoneme /a/ considered the least facilitative of all phonemes, only the velum can provide the function of sphincter and resonator. The a/z ratio therefore measures glotto-velar efficiency on phonatory efficiency as a whole; we call it glotto-velar phonatory efficiency.

Link with the velum

In the case where the soft palate is hypo-functional, the duration of /a/ will decrease drastically because of the drop in supraglottic pressure. The larynx will compensate as best it can for this loss of efficiency by contracting in a deleterious compensatory behavior and the comparative tests risk deterioration due to fatigability effect. Instability will appear and even interruptions in the phonation. This clinical picture is observable in subjects with cleft palates or velar insufficiency [Rousteau 2017] or in patients with hypokinetic type dysarthria. In summary, the two performance measures s/z and a/z are complementary and inseparable. They allow measurement of the pressure of the vocal tract in 3 extreme configurations, which occur frequently in speech.

By correlating these measurements with the quality indicators implemented in VOCALAB [Sicard 2022], we can deduce very important information such as: how the source behaves with velar impedance or lingual impedance and above all where the problem is located. Its identification will be decisive for the choice of therapeutic axes. On the other hand, qualitative elements such as signs of effort and fatigue (shortness of breath, comments, relief when the test ends) as well as the comparison of durations during the tests and during the test will alert us on phonation issues. The advantage of providing strict instructions and a constrained protocol is to reassure clinicians and allow them to interpreting accurately measurements during therapy.

Implementation

In the VOCALAB tool, the *Phonation Time* module allows the clinician to record 3 successive samples of /a/, /s/ and /z/, then, once the 9 trials are completed, to calculate the averages, the pathology indicators, as well as the a/z and s/z ratios. The results can be integrated into the assessment sheet as well as the progress sheet before/after speech therapy.

MPT pathological indicators

The reference values are different depending on the gender and age of the patient. The thresholds fall below 15 years and above 65 years. The pathology indicators on /a/, /s/ and /z/ evaluate the distance between the average performances of the patient and the norm. The color code used for these indicators is reported in Table 9. For normal speaking duration, the indicator is below 1.0, regardless of gender and age. The higher the performance, therefore the longer the speaking time, the lower the pathology index.

Pathology indicator	Color	Signification
< 0.8	Green	Normal MPT, above limit normal/impaired
0.8-1.4	Orange	MPT limit normal/impaired
> 1,4	Red	MPT below impaired/pathological limit

Table 9: Meaning of the pathology index values of the Phonatory Time module

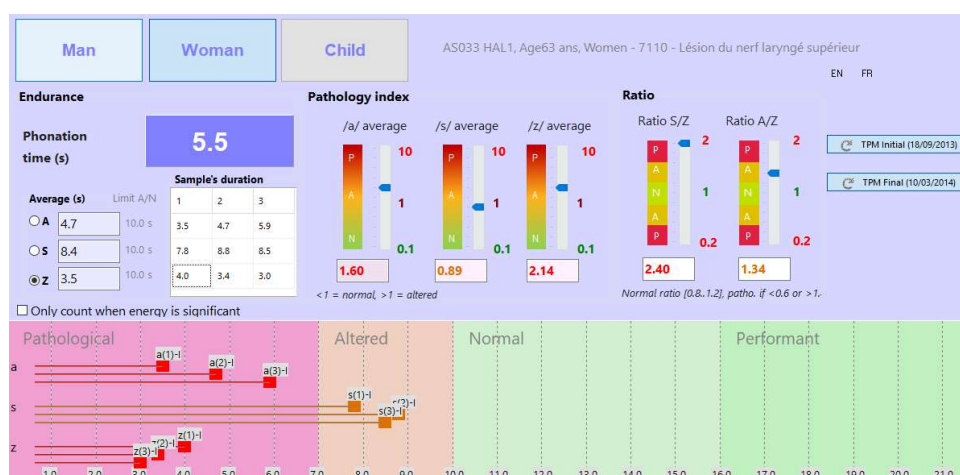


Figure 13: Pathology indicators associated with the durations of /a/, /s/ and /z/, and associated ratio, case AS033, 63-year-old woman, before therapy

Pathology indicators of s/z and a/z ratios

The s/z and a/z ratio indicators use color codes whose correspondence with the calculated value is illustrated in Figure 14. The numbers appear in green only for values between 0.8 and 1.2, then in orange between 0.6 and 1.4, in red beyond. In the example of case AS033 (Figure 13), the s/z ratio is red because it is much greater than 1.6, and the a/z ratio is orange because it is between 1.2 and 1.4.

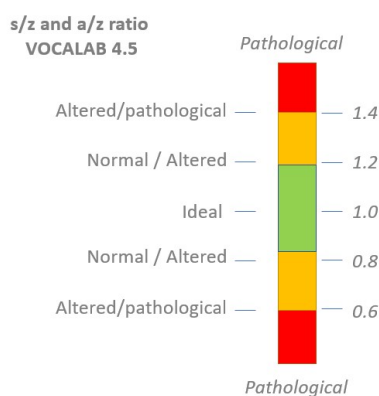


Figure 14: Color coding according to s/z and a/z ratio values in VOCALAB

Evolution of MPT with therapy

In table 10, we provide a summary of the observations extracted from different studies before treatment (PRE) then after treatment (POST), concerning speech time (MPT) and the s/z ratio.

PATHOLOGY	REFERENCE	CORPUS	MPT PRE	MPT POST	NORM MPT	S/Z PRE	S/Z POST	NORM
VOCAL CORD INJURY	[Virmani 2016]	19 H 11 F	9,43	14,5	>12,5 >10,5	1,37	1,15	0.8-1.2
VOICE DISORDERS	[De Oliveira Lemos 2017]	8 H 22F	7,91 8,15	10,8 10,6	>12,5 >10,5	30%<0.8 23%>1.2	90% normal	0.8-1.2
DYSPHONIA	[Niebudek 2008]	186 F	13,3	16,6	>10,5			
NODULES, POLYPS	[Watts 2015]	8 F	12,4	15,5	>10,5	1,47	1,05	0.8-1.2
VOCAL FUNCTION	[Verma 2010]	62 H 38 F	14 10	16,3 13,3	>12,5 >10,5	1,27	1,04	0.8-1.2

Table 10: Summary of different studies showing the impact of therapy on speech time and the s/z ratio

Thirty adult patients with minor vocal disorders (8 men, 22 women) were treated according to standard voice therapy protocols for 6 months in [De Oliveira Lemos 2017]. Before therapy, only 47% of s/z ratios were in the range 0.8-1.2, a figure which rose to 90% after therapy. Note that the MPT of sustained /a:/ progresses, with women passing on average above the altered/normal threshold.

Thirty adult patients (19 men, 11 women, average age 42 years) with vocal cord lesions (polyps, nodules, cysts) were treated according to standard speech therapy protocols in [Virmani 2016]. The MPT measurement on /a/, /s/ & /z/ was done before treatment, then at 3 and 6 months of therapy. The MPT on /a:/ increased from 9.4 seconds to 14.2 seconds at 3 months and 14.5 seconds at 6 months. The S/Z ratio was reduced from 1.37 to 1.16 at 3 months and 1.15 at 6 months.

The study by [Niebudek 2008] involving 186 teachers aged 23 to 60 (mean age 39) with voice disorders, showed a significant increase in maximum phonation time after completing a voice training program specifically designed for their profession. Improved performance in terms of phonation time and s/z ratio were found by [Watts 2015] in a study involving 8 women benefiting from a vocal therapy once per week for 6 weeks. Finally, we can cite the effects of phono-vocal cord surgery on patients reported by [Verma 2010] where a significant improvement in MPT and an s/z ratio returning to normal was observed after surgery for around 100 patients.

We present in Figures 15 & 16 the performances of a 9-year-old girl concerning the phonatory time on /a/, /s/ and /z/, according to the normal, altered or pathological phonation time thresholds. Figure 15 corresponds to the AS051 case before therapy: the performance of /a:/ is very low, the values of /s:/ are very low, but /z:/ is close to the norm. Both s/z and a/z ratios are very far from 1, and the s/z ratio is very low.

After speech therapy (figure 16), the maximum phonation time hardly improves regarding /a:/, but the 3 realizations of /s/ and /z/ pass into the normal zone after treatment. The s/z ratio has returned to the nominal 0.8-1.2 range, but the a/z ratio remains very low.

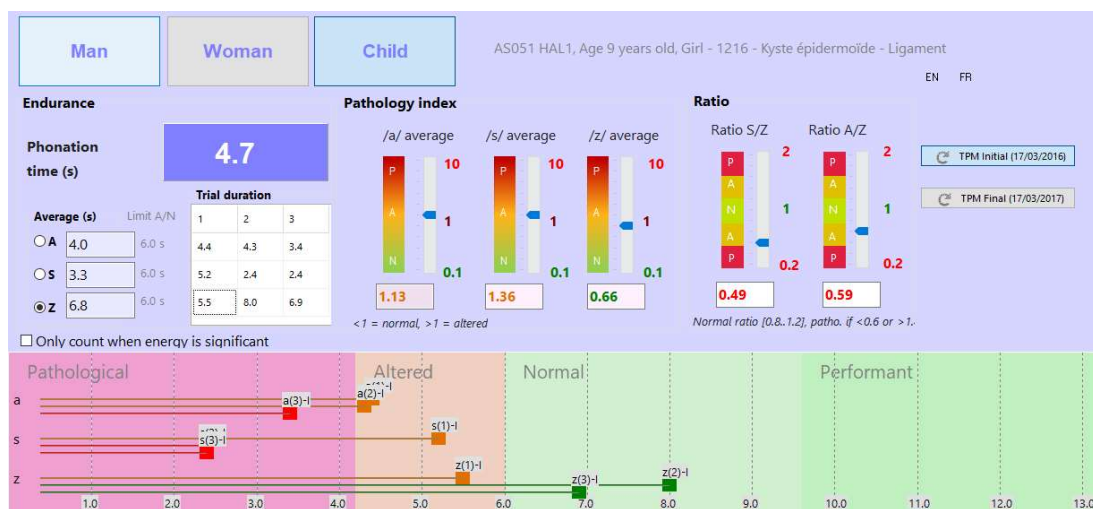


Figure 15: Maximum phonation time measured on 3 successive recordings of /a:/, /s:/ and /z:/, case study AS051, before speech therapy [Menin-Sicard 2021]

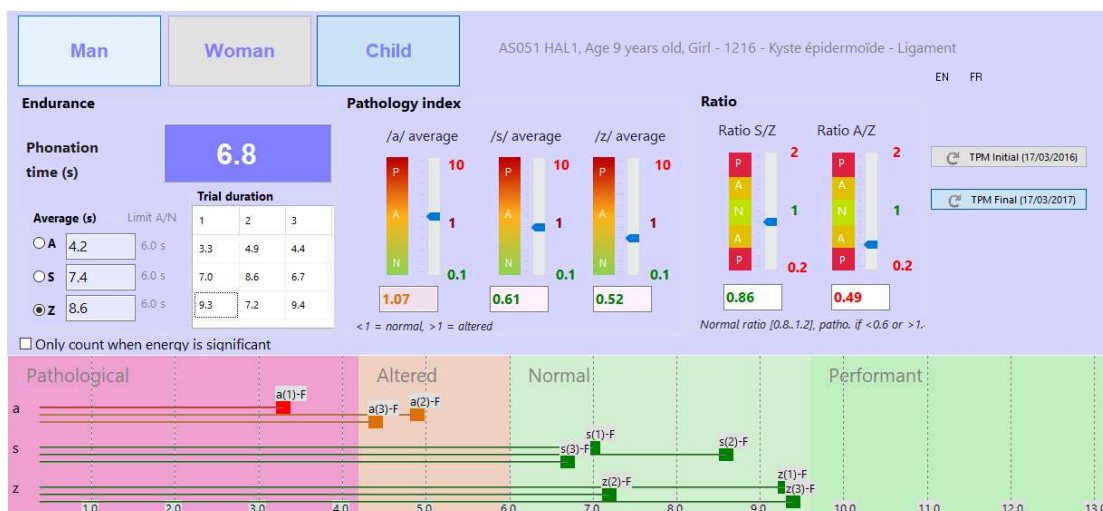


Figure 16: Maximum phonation time measured on 3 successive recordings of /a:/, /s:/ and /z:/, case study AS051, after speech therapy [Menin-Sicard 2021]

Discussion

The voice recording conditions, the settings of the sound acquisition chain and the signal processing algorithms have an impact on the reliability, reproducibility, and validity of objective analyses. We can however consider that very simple analyzes such as measuring the maximum phonatory time and s/z and a/z ratios studied in this article are more influenced by the variability of the protocols for administering these tests, than by the computer tool itself.

We have underlined the interest of carrying out 3 successive recordings of the same phoneme (3 /a:/, followed by 3 /s:/, and 3 /z:/). We recommend to avoid giving a model, but be very precise in the instructions given to the patient, using identical terms, so the performance comparison before/after therapy can be considered as relevant.

The analysis of maximum phonation time and associated s/z or a/z ratios should not focus only on raw values, but must also consider the quality of phonation, or other objective parameters. The alteration indicators extracted from the sustained, including attack, instability in pitch (*Jitter*), amplitude (*shimmer*), noise/harmonic ratio (NHR) and harmonic poverty should also be considered, as described in [Sicard 2021].

The instrumentation to be used includes a directional microphone, a low-noise and high bandwidth sound card, with optimal setting to benefit of the maximum dynamics of the voice recording. In VOCALAB, instructions for a robust and efficient protocol have been implemented, which clarify the vocal tasks to be performed by the patient, and maximize the relevance of measured performances, which further enable fair comparison of MPT before and after speech therapy. We gathered a large base of scientific data concerning men, women, and children from which we extracted general trends for MPT. We fixed what we consider as reasonable thresholds for normal, altered, and pathological phonation times for all ages.

However, the proposed thresholds should not be considered as rigid limits, with a binary approach such as functional MPT above a certain value, and non-functional MPT below. The great variability of the results extracted from scientific publications and the numerous possible approaches to calculating the MPT may lead to consider a “gray” zone around the proposed thresholds. Anyhow, the favorable evolution of metrics such as the increase in speaking time or the return of s/z and a/z ratios to a balanced value constitute conclusive indications of the effectiveness of speech therapy.

Conclusion

Due to the variability of the data available on the maximum phonation time, it seemed necessary to compile many results published in the form of a summary graph, to extract overall trends according age and gender. We mixed data obtained using different protocols and calculation methods that could either reduce or increase the values, but we hoped that the large number of publications would make it possible to circumvent the difficulty of comparing the data between each other, and extract general trends.

We were thus able to extract a maximum phonation time on the vowel /a:/ of around 25 seconds on average for men, and 20 seconds on average for women, all studies combined, in the 15–65-year range. These values tend to decrease with age. From the trend curve, and considering the statistical strength of the studies, we defined a normal/altered level around 12 seconds for men, 10 seconds for women, as well as an altered/pathological level of 8 seconds for men and 7 seconds for women. These values were integrated into the MPT module of VOCALAB software.

We also carried out a study of the s/z and a/z ratios published in the scientific literature, generally finding values close to 1 for normal phonation, which was nearly independent of age and gender. The analysis of scientific publications has also shown a trend towards an increase in the s/z ratio, mainly for pathologies such as nodules, cysts, or edema of the vocal cords, although some examples of very low s/z or a/z ratios were also mentioned. Through some studies on the effectiveness of speech therapy treatment, the metric of maximum phonation time and the s/z ratio have proven to be of interest in supporting the objective evaluation of progress during speech therapy. We finally defended the interest of the a/z ratio, less covered in the literature, as another interesting metric of the phonation assessment.

Acknowledgements

We acknowledge the efforts to publish in open archives a very large number of scientific results, in the field of voice and speech, which allows very wide and simple dissemination at no cost, enabling comparative analyzes and meta-analyses which accelerate their clinical application.

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Appendix A – Maximum Phonation Time - Men

<i>Average age</i>	<i>Number of people</i>	<i>MPT (s)</i>	<i>Standard dev (s)</i>	<i>Sources</i>
3	5	7,9	1,8	Finnegan
4	10	10,0	2,5	Finnegan
5	10	10,1	3,0	Finnegan
5,5	185	6,0	1,8	Tavares
6	9	13,9	3,0	Finnegan
6	44	10,4	5,1	Harden
7	9	14,6	2,8	Finnegan
7	10	14,2	3,3	Beckett
8	10	16,8	6,0	Finnegan
8	10	20,0	8,0	Lewis
8,5	483	8,1	2,0	Tavares
9	10	16,8	6,1	Finnegan
10	10	22,2	4,7	Finnegan
10	10	24,9	7,0	Lewis
11	10	19,8	3,8	Finnegan
11	156	9,2	2,3	Tavares
12	9	20,2	5,7	Finnegan
13	10	22,3	8,2	Finnegan
14	10	22,3	6,9	Finnegan
15	10	20,7	5,3	Finnegan
16	10	21,0	4,4	Finnegan
17	10	28,7	7,1	Finnegan
21	30	27,5	8,7	Moreno
22	30	28,4	11,1	shanks
22	30	17,1	5,9	Cunha
22,5	10	21,8	8,0	Johnson
23	31	24,6	6,7	Ptacek
24	5	22,6	6,1	Isshiki
25	10	31,6	7,9	Rau
25	76	20,4	9,0	Knuijt
26	5	32,0	7,5	Isshiki
29	21	17,8	2,2	Lechien
32	40	24,9	9,5	Ptacek
32	33	18,1	6,2	Karlsen
35	28	22,5	9,0	Knuijt
35	35	22,2	9,2	Daubison
37	11	30,2	9,7	Yanagihara
39	30	26,5	5,9	Moreno
45	27	23,0	9,0	Knuijt
50	31	16,6	1,1	Lechien
55	5	15,4	5,0	Mueller
55	37	21,6	9,0	Knuijt

55	187	16,6	6,8	Laganaro
65	7	26,2	7,0	Maslan
65	30	23,8	9,0	Knuijt
65	10	18,4	6,8	Johnson
67	19	14,4	5,5	Pessin
68	16	11,3	6,3	Fang
68	17	17,2	8,6	Siqueira
69	28	18,7	2,2	Lechien
70	16	18,6	3,0	Dagli
70	10	14,6	5,5	Kreul
71	30	24,1	10,0	Moreno
71	27	18,1	6,6	Ptacek
72	7	17,4	5,6	Fox
72	11	13,3	5,3	Alves
75	26	20,0	9,0	Knuijt
80	10	20,0	9,0	Morsomme
83	13	13,7	4,8	Pessin
85	14	21,7	1,5	Maslan

Note: In some studies, male and female MPTs are not differentiable, the average was reduced by 2 seconds for women and increased by 2 seconds for men. The age in the 1st column corresponds to the average age of the corpus. Ancient sources are compiled in [Kent 1987].

Appendix A – Maximum Phonation Time - Women

<i>Average age</i>	<i>Number of people</i>	<i>MPT (s)</i>	<i>Standard dev (s)</i>	<i>Sources</i>
4	10	8,7	1,8	Finnegan
5	10	10,5	2,6	Finnegan
5,5	204	6,2	2,0	Tavares
6	9	13,8	3,6	Finnegan
6	58	10,6	6,3	Harden
7	10	13,7	2,4	Finnegan
7	10	15,4	2,7	Beckett
8	10	17,1	4,6	Finnegan
8	10	19,1	5,0	Lewis
8	7	16,7	3,0	Reich
8,5	473	7,9	2,0	Tavares
10	9	14,5	3,8	Finnegan
10	10	15,9	6,0	Finnegan
10	10	16,5	3,0	Lewis
11	10	14,8	2,1	Finnegan
11	159	9,1	2,0	Tavares
12	10	15,2	3,9	Finnegan
13	10	19,2	4,6	Finnegan
14	10	18,8	5,2	Finnegan
15	10	19,5	4,7	Finnegan
16	10	21,8	4,5	Finnegan
17	10	22,0	6,3	Finnegan
21	30	23,5	8,7	Moreno
22	30	14,3	4,5	Cunha
22,5	10	17,8	8,0	Johnson
23	30	21,5	6,4	Shanks
24	9	24,8	5,4	Rau
25	5	15,2	5,0	Isshiki
25	76	16,4	7,4	Knuijt
28	31	20,9	5,7	Ptacek
28	21	13,8	2,2	Lechien
28	10	22,0	4,2	Peppard
30	40	17,9	6,4	Ptacek
31	11	22,5	6,1	Yanagihara
33	10	26,0	8,0	Stemple
35	28	18,5	7,4	Knuijt
35	65	16,1	6,2	Karlsen
39	30	22,5	5,9	Moreno
40	41	18,4	7,3	Daubison

45	27	19,0	7,4	Knuijt
49	31	12,6	1,1	Lechien
50	25	25,7	7,0	Hirano
55	37	17,6	5,0	Knuijt
55	202	14,7	5,8	Laganaro
65	7	18,8	7,0	Maslan
65	30	19,8	7,4	Knuijt
65	10	14,4	6,8	Johnson
67	25	10,4	5,5	Pessin
68	39	12,7	7,3	Siqueira
69	28	14,6	2,2	Lechien
70	12	14,6	5,8	Kreul
70	7	17,9	5,0	Fox
70	4	16,8	2,8	Dagli
71	30	20,1	10,0	Moreno
72	44	13,1	5,8	Alves
75	26	16,0	7,4	Knuijt
75	13	22,8	6,0	Maslan
80	36	14,2	5,6	Ptacek
83	15	9,7	4,8	Pessin
85	30	12,0	5,0	Morsomme
85	14	20,6	3,0	Maslan

Note: In some studies, male and female MPTs are not differentiable, the average was reduced by 2 seconds for women and increased by 2 seconds for men. The age in the 1st column corresponds to the average age of the corpus. Ancient sources are compiled in [Kent 1987].

Appendix C – s/z ratio men

<i>Age</i>	<i>s/z ratio</i>	<i>Reference</i>
5	0,92	Tait 1980
5,5	0,97	Tavares 2012
7	0,7	Tait 1980
8,5	0,95	Tavares 2012
9	0,92	Tait 1980
9,2	0,97	Salihovic 2009
11	0,99	Tavares 2012
22	1,02	Cunha 2019
28	1,07	Joshi 2020
30	0,99	Eckel 1981
33	1,04	Verma 2010
35	0,94	Asnaashari 2012
38	0,96	Shrestha 2019
42	1,15	Virmani 2016
57	1,01	De oliveira Lemos 2017
67	0,83	Pessin 2017
68	0,76	Fang 2014
68	1,1	Siqueira 2020
72	1,01	Alves 2015
83	0,93	Pessin 2017

Note: in some studies, the male and female s/z ratios are not differentiable. Ancient sources are compiled in [Kent 1987]. The age corresponds to the average age of the corpus.

Appendix D – s/z ration women

<i>Age</i>	<i>s/z ratio</i>	<i>Reference</i>
5	0,83	Tait 1980
5,5	0,96	Tavares 2012
7	0,78	Tait 1980
8,5	0,99	Tavares 2012
9	0,91	Tait 1980
11	1,01	Tavares 2012
21	1,09	Van Wyk 2017
22	0,96	Cunha 2019
29	1,09	Joshi 2020
30	0,99	Eckel 1981
33	1,04	Verma 2010
35	0,94	Asnaashari 2012
42	1,15	Virmani 2016
57	1,01	De Oliveira 2017
67	0,83	Pessin 2017
68	0,89	Siqueira 2020
72	0,99	Alves 2015
80	0,82	Young
83	0,93	Pessin 2017

Note: in some studies, the male and female s/z ratios are not differentiable. Ancient sources are compiled in [Kent 1987]. The age corresponds to the average age of the corpus.

Appendix E – MPT implemented in VOCALAB

