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# The balloon in the box model; exponential factors in voice control

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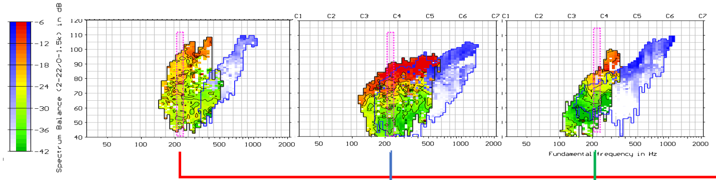
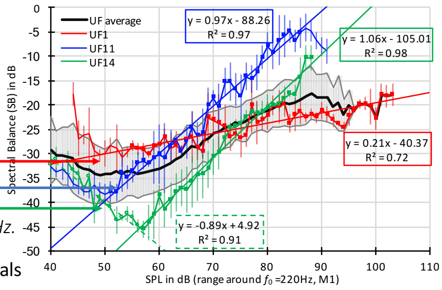
Voice maps with Spectrum Balance in dB (color) vs. log($f_0$) & SPL for three untrained female voices in M1

*From: Pabon & Ternström, Feature Maps of the Acoustic Spectrum of the Voice, J Voice 2018*



### Spectrum Balance versus SPL only



*To derive the -> plot of Spectrum Balance vs SPL only a vertical slice is taken around $f_0$ = 220 Hz.*

Note: exponents vary largely between individuals, but are very reproducible within individuals

**Log/Log scale mapping exposes regimes with different linear exponential dependencies**

Acoustic power (SPL) measured at a fixed source distance represents the energy level of the combined system of vibrating vocal folds and air column, scaled by a radiation factor.

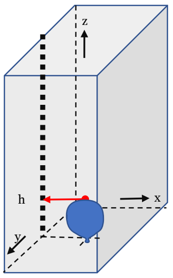
SPL can be seen as a probe of the "acoustic temperature" in the voice production container.

Questions:

How come that voices show different characteristic exponents and offsets?
What could be a possible explanation for the regime changes?

## A model that demonstrates a comparable behavior:

Balloon in a rectangular box as an example of a system that will show regimes with different linear exponential dependency between it's parameters.



**Thermodynamic equating**

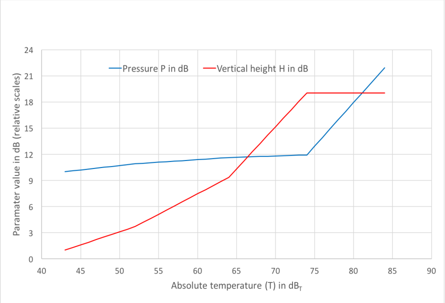
In thermodynamic modeling, there are no additive or subtractive terms at both sides of the equal sign. Thermodynamic modelling centers around equating the *exponential scaling factors* of macroscale parameters, called *measures*, that reflect the integrated effects of microscale dependencies.

Here the universal (ideal) gas law applies:

$$P \cdot V = n \cdot R \cdot T$$

On logarithmic (dB) scales this dependency linearizes to:

$$10log_{10}(P) + 10log_{10}(V) = 10log_{10}(n) + 10log_{10}(R) + 10log_{10}(T)$$



*Predicted changes as a result of raising the temperature of the gas in this closed system. Vertical height in dB, and balloon pressure P in dB as a function of the log of absolute temperature in dB. The breakpoints S mark changes in regime. Note that the pressure and balloon-height curves do not share a common reference or zero-dB point and each have an arbitrary vertical offset.*

Checkout the video to see how the breakpoints in the curve mark the points where a DOF is lost and from where a new power balancing regime settles.

### Applying a thermodynamic model to voice production

The approach is different. The statistical mechanical integration that is part of the abstraction process helps you to focus on the elements of the implementation that matter for balancing the efficiency of the power conversion process from subglottal pressure to acoustical pressure.

### Useful inferences that you might immediately get or may ask me to explain:

- Bounding changes the *exponents* in the power conversion process.
- With a different box geometry, the breakpoints will shift.
- With a conical shaped box, exponents connected with the linear regimes will be different.
- Differences in VF geometry and stiffness along different axes will comparably translate to different exponentials in parametrized dependencies.
- A change in dimensionality or DOF (VF's start to contact, VF amplitude limits, VF motion loses longitudinal sync) could imply both a positive or a negative change in the exponential factors that determine the efficiency of the conversion mechanism from subglottal pressure to acoustic pressure.
- Mechanical or aerodynamic bounds don't mark endpoints on a scale as they a do not *directly* limit the power produced.
- The highest SPL we can produce at a given $f_o$ is never a hard limit but an *indirect* reflection of the system losing potential to efficiently increase on the level with the given input and power equating setting.
- $P_{sub}$ *is essentially a volumetric control*, variable exponent ≤ 3 depending on the VF geometry (in most models it is a fixed one-dimensional control).
- Models based on a 1-D or 2-D geometry are no first approximation as they cannot predict the exponents connected to the control parameters, nor the regime changes that result from the effect of bounding a degree of freedom.
- *None of the parameters that control the voice is an absolute control* or can be associated with a fixed exponent in dB per proportion of another control.
- A flat curve on log/log-scales implies no change in exponential factor in a relation to another parameter. Invariance in exponent does not imply that a parameter is behaving independently or is unaffected by the other parameter, it means varying in constant proportion with and thus in close correspondence.
- All voice parameters remain coupled and mutually dependent, but their influence may change dynamically.

*Read more on this subject in ch5 of my Thesis: Mapping Individual Voice Quality over the Voice Range, the Measurement Paradigm of the Voice Range Profile.* urn:nbn:se:kth:diva-235824