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A Short Tutorial on Sound Level and Loudness for Voice

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Sound pressure level (SPL) is often used as a physical measure of vocal loudness. It measures an acoustic (oscillatory) pressure in reference to an internationally agreed upon standard, 20 micro Pascal (20 μPa). The exact relation is

$$SPL = 20 \log_{10} (P/P_0) \quad dB$$

where P is the measured pressure and P_0 is the reference pressure. The logarithm and the multiplication by 20 are chosen so that the dB numbers fall conveniently into a 0–100 range for many sounds we are exposed to on a regular basis, but numbers up to 150 dB are possible for very loud sounds.

In most cases in free space, SPL also measures the sound intensity, the sound power distributed over a surface area. Sound intensity level is defined as

$$SIL = 10 \log_{10} (I/I_0) \quad dB$$

where I is the sound intensity in watts per square meter (W/m^2) and I_0 is another internationally agreed upon standard, 10^{-12} W/m^2. The two standards are chosen such that SPL and SIL give the same number in dB. In fact, one can generally drop the reference to pressure or intensity and simply talk about sound level (SL). A sound level meter (SLM) does just that. Any dB reading can be converted to either pressure or intensity.

Sound level can help explain several important phenomena in singing. Questions of interest are: (1) How does sound level change with fundamental frequency and lung pressure? (2) How does sound level change when there are multiple sound sources? (3) How does sound level change with distance from a source? (4) How does sound level relate to perception of loudness? To answer these questions in detail would require a complete textbook, or at least a chapter (e.g., *Principles of Voice Production*, Chapter 9).[1] Some quick rules of thumb can be given here, however.

With regard to fundamental frequency, SL increases about 6 dB/octave, all else being equal. This is the primary reason why females often outsing males on the opera stage if they sing an octave higher. Males may produce more glottal airflow, but it is the rate-of-change of airflow that determines the acoustic power. Higher frequency produces a higher rate of change of airflow.

With regard to lung pressure, SL increases about 6–9 dB with every doubling of lung pressure.[2] The major phenomenon here is increase in peak glottal airflow. Higher peak airflow results in a greater rate-of-change of airflow (from peak flow to zero prior to glottal closure). The rate of change is also known as maximum flow declination rate (MFDR), which is measureable.[3]

With regard to the addition of two or more sound sources, the instantaneous pressures add together, but this addition is complicated because the waves may differ in amplitude (the amount of increasing and decreasing pressure each wave has), in frequency (how rapidly the pressure increases and decreases), and in phase (where in the cycle of oscillation the wave is at a given instant of time). A good microphone is responsive to all of these variables. For example, if the amplitudes and frequencies are the same, the pressure doubles if the waves are in phase and the pressure is zero if the waves are out of phase. For the in-phase situation, the SL increases by 6 dB over the SL of either of the two sounds individually ($20 \log_{10} 2 = 6$). For the out-of-phase situation, the SL meter would read nothing. Often, however, the phase varies so much between two sounds that the sounds are incoherent (the scientific term); in such cases, the individual powers can be added without consideration of phase. Two waves of equal amplitude and frequency will then have a combined sound level of +3 dB over either wave individually ($10 \log_{10} 2 = 3$). This is the typical situation in ensemble singing. If we double the number of singers, we double the sound power, which raises the combined SL by 3 dB.

Change of SL with distance from the source is explained by the inverse-square law. Since sound intensity measures the distribution of sound power over a surface, one watt (W) of sound power distributed over a small area has a greater intensity than 1 W distributed over a large area. The earliest acoustic hearing aids were funnels (inverted megaphones) that increased the intensity at the eardrum (small area) by gathering sound with a larger area (wide end of megaphone). Sound intensity varies dramatically with distance from a localized sound source. If the sound power produced at the mouth of a singer or speaker is constant, the sound intensity varies inversely with the square of the distance from the mouth. This produces a 6 dB loss in SL for every doubling of distance. For example, a person standing 4 feet from a microphone produces 6 dB less SL than a person standing 2 ft from a microphone. But the relation is more complex with very close mouth-microphone distances. Near-field effects take over, which are beyond the scope of this tutorial.

The human auditory system perceives sound intensity or pressure in terms of loudness; however, tones of equal SL do not have equal loudness. Low frequency tones (around 100 Hz) require 10–20 dB more SL than mid-frequency tones (500–3000 Hz) to be perceived with equal loudness. High-frequency tones (above 10,000 Hz) also require more SL than mid-frequency tones. At any one frequency, loudness perception roughly doubles with every 10 dB increase in SL. To complicate matters, the frequency spectrum (higher partials) also affects loudness perception if the sound is more than a simple tone. Spectrally rich sounds (lots of high frequency partials) are perceived louder than spectrally poor sounds (few partials).

In summary, doubling sound sources (more singers or more loudspeakers) buys you only 3 dB, doubling your lung pressure buys you 6–9 dB, doubling your pitch buys you 6 dB, and getting into the sensitive region of a person's auditory system (250–4000 Hz) can buy you extra loudness without increase in SL.

NOTES

1. Ingo R. Titze, "Control of Vocal Intensity and Efficiency," in Ingo R. Titze, *Principles of Voice Production* (Iowa City: National Center for Voice and Speech), 243.
2. I. R. Titze and J. Sundberg, "Vocal Intensity in Speakers and Singers," *Journal of the Acoustical Society of America* 91, no. 5 (May 1992): 2936–2946.
3. E. B. Holmberg, R. E. Hillman, and J. S. Perkell, "Glottal Airflow and Transglottal Air Pressure Measurements for Male and Female Speakers in Soft, Normal, and Loud Voice," *Journal of the Acoustical Society of America* 84, no. 2 (April 1988): 511–529; E. T. Stathopoulos and C. Sapienza, "Respiratory and Laryngeal Function of Women and Men during Vocal Intensity Variation," *Journal of Speech and Hearing Research* 36, no. 1 (February 1993): 64–75.