Experienced Saxophonists Learn to Tune Their Vocal Tracts

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How much do the acoustics of the vocal tract influence performance on single-reed instruments (clarinets and saxophones)? To summarize a 25-year debate, we note that scientists' opinions have ranged from "negligible" (*1*) to "vocal tract resonant frequencies must match the frequency of the required notes" (*2*). Musicians' opinions are also diverse. The longevity of the debate is due to the difficulty of making nonperturbing, precise acoustical measurements inside the mouth during playing (*3*), that is, in a variable, humid environment with very loud sounds.

The notes played on wind instruments depend on the acoustic impedance, Z: the ratio of sound pressure to the oscillatory component of air flow. Reed instruments usually play at frequencies very near a high, sharp peak in the impedance spectrum of the bore of the instrument. In a standard simple model (*4*), the impedance of the vocal tract, Z_t, is in series with that of the bore, Z_b. For most playing conditions, Z_b is much larger than Z_t (e.g., Fig. 1A), so acousticians usually neglect the role of the tract.

In saxophones and clarinets, a single reed vibrates to modulate the flow into the instrument and is in turn driven to vibrate by standing waves in the bore of the instrument. We studied the tenor saxophone, whose mouthpiece is large enough to support devices that we constructed for measuring Z_t with minimal perturbation to the player. Five professional and three amateur saxophonists sustained notes for several seconds while we measured Z_t by using an acoustic signal comprising 224 sine waves (*5*–*7*).

In Fig. 1, (A) and (B) show typical experimental data. The dark line is Z_t. Upon this are superimposed narrow spikes, which are harmonics of the note being played. The pale line shows Z_b for that note.

Over the lower-frequency range of the instrument, the peaks in Z_b are much greater than those in Z_t. Also in this range, the peaks in Z_t varied greatly among players and showed no consistent relation to the note played (Fig. 1, A and C). In the high (altissimo) range, however, the professional players consistently tuned a strong peak in Z_t near to or slightly above the fundamental of the note played (Fig. 1C).

The amateur players, who did not tune a strong peak in Z_t, were unable to play in the altissimo range. A configuration of keys pressed (a fingering) produces a Z_b with several peaks, whose magnitudes decrease at high frequency. In the normal range, the peak of Z_b at the appropriate frequency is large and dominates the series combination ($Z_b + Z_t$). In the high range, the relevant peak in Z_b is weak (Fig. 1, A and B, are representative). Here, experienced players use a peak in Z_t, which may be several times greater than that in Z_b, to choose the playing frequency. For instance, experienced players can hold a single fingering and play a different note at each of the first dozen peaks in Z_b by tuning Z_t.

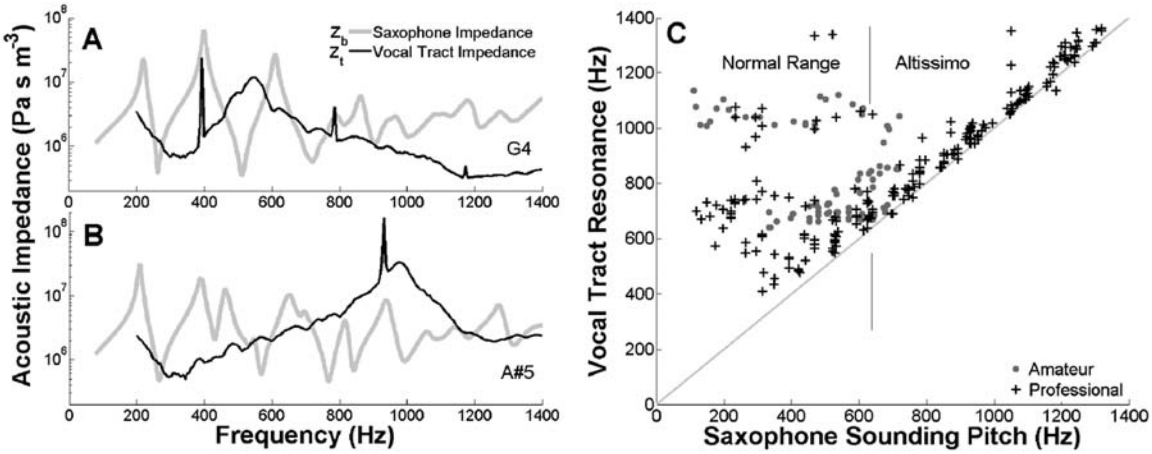

Fig. 1. Representative examples of acoustic impedances of the tract (Z_t) for a professional player (**A**) for the note G4 (near 400 Hz, in the normal range) and (**B**) for the note A#5 (near 940 Hz, altissimo range) (sound files in supporting material). The narrow peaks are harmonics of the notes played, the broad peaks are tract resonances. Z_b for the saxophone for each note is shown with a pale line. (**C**) The frequencies of the relevant resonance in the vocal tract are plotted against the frequency of the note played. The diagonal line shows the equation: tract resonance frequency = pitch frequency.

We conclude that the vocal tract resonances have only modest effects on the sounding pitch over much of the instrument's range. However, to play notes in the altissimo range, players learn to tune a resonance of the tract near to the note to be played. Although demonstrated only for saxophone, similar effects are likely to be important in other single- and double-reed instruments, whose players also report the importance of the tract for special effects, including high-register playing.

References and Notes

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7. Materials and methods are available on *Science* Online.
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Supporting Online Material

www.sciencemag.org/cgi/content/full/319/5864/776/DC1
Materials and Methods
Fig. S1
References
Audio S1 to S4

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