Ingo's Register Treadmill

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A register treadmill was proposed eight years ago as a diagnostic exercise for exposing involuntary register shifts in the D_4 to A_4 pitch range.[1] The basic concept was to create pitch and vowel progressions that would elicit maximum crossings of harmonics with supraglottal resonances (formants) of the vocal tract. It is well known that sudden increases or decreases in harmonic amplitudes in proximity of a resonance can cause a timbral change that can be considered an acoustic registration.[2] In particular, strengthening or weakening the second harmonic with the first formant can be responsible for such a register shift. A penta-vowel sequence, combined with a pentatonic scale, was proposed such that source frequencies move in opposite direction to resonance frequencies. This produces multiple harmonic-resonance crossovers.

This article is a follow-up to expand the treadmill to include a wider pitch range and sex differences in formant frequencies. While allophonic variations of formants F_1 and F_2 are large across individuals and languages, a smoothed penta-vowel sequence has been chosen here. Each sequence begins with a wide mouth shape and ends with a narrow mouth shape. Formant frequencies for females have been chosen to be 20 % higher than for males. All formant frequencies are listed below for two vowel sequences.

High Vowel Sequence	[æ]	[ɛ]	[e]	[ɪ]	[i]
Male F_1	670	550	420	350	280
Female F_1	860	660	504	420	320
Male F_2	1800	1900	2000	2200	2300
Female F_2	2160	2280	2400	2640	2760
Low Vowel Sequence	**[a]**	**[ɔ]**	**[o]**	**[ʊ]**	**[u]**
Male F_1	850	500	360	300	300
Female F_1	1020	600	431	360	370
Male F_2	1610	800	640	610	595
Female F_2	1932	960	768	732	714

In the treadmill, F_1 is descending while f_o is ascending to produce a maximum number of harmonic/formant crossings. Figure 1 shows the graphic display for a D_4–A_4 up and down pentatonic scale (solid lines), combined with the low vowel formant frequencies (dashed lines). Note that there are

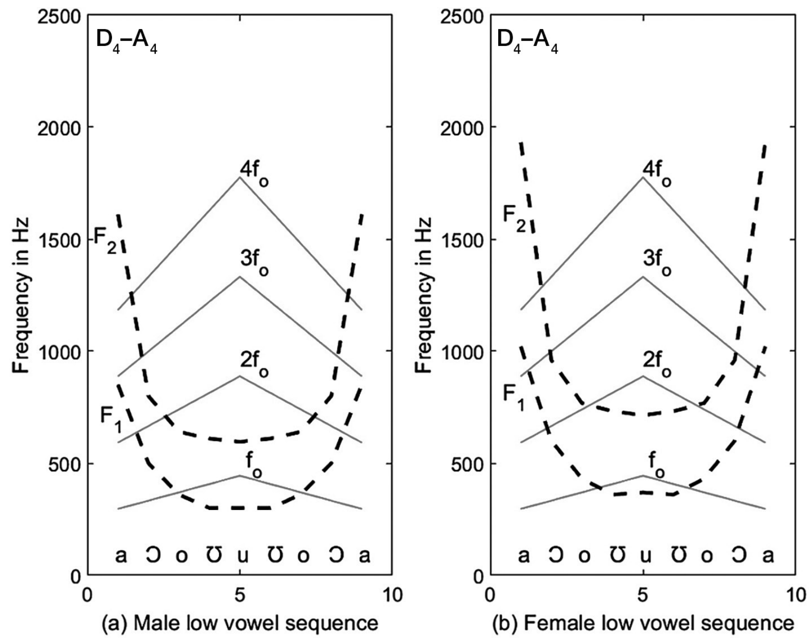

Figure 1. **Treadmill for the D_4–A_4 pentatonic scale produced on low vowels; (a) male sequence and (b) female sequence.**

five crossings on the ascending scale for both males and females. For males, the crossings are:

f_o crosses F_1 near the [o] vowel; $2f_o$ crosses F_1 near the [ɔ] vowel

$2f_o$ crosses F_2 near the [o] vowel

$3f_o$ crosses F_2 near the [ɔ] vowel

$4f_o$ crosses F_2 near the [ɔ] vowel.

Note the importance of the [ɔ] and [o] vowels in males in this region of the pitch range.

For females, the same five crossings occur, but on slightly more closed-mouth vowels due to higher overall formant frequencies. For example, f_o crosses F_1 closer to the [ʊ] vowel than the [o] vowel.

Figure 2 shows the treadmill for the high vowel sequence. The pentatonic scale is kept the same, D_4–A_4. There are now only two major crossings:

f_o crosses F_1 between [e] and [I] in males and between [I] and [i] in females;

$2f_o$ crosses F_2 between [æ] and [ɛ] in males and between [ɛ] and [e] in females

None of the first 4 harmonics cross the second formant F_2. Thus, in this region of the pitch range (D_4–A_4), acoustic registration in high vowels is carried primarily by the first two harmonics. The fifth and higher harmonics are not plotted. They will interact with F_2 and higher formants, particularly if f_o is raised.

Figures 3 and 4 show the treadmills when the pentatonic scale is raised to the G_4–D_5 range. Usually one progresses in half-steps to this higher level. Most of the high pitch range for males and female belters is then covered. Figure 3 shows the low vowel sequence. The bright [a] vowel is now included in the crossings, but the general picture has not changed much from the A_4–D_4 scale. Of special interest are the [ʊ] and [u] vowels, for which the fundamental frequency f_o approaches the second formant frequency F_2. A crossing does not occur for the vowels chosen, but the proximity to F_2 strengthens the fundamental f_o. Some tenors are very comfortable practicing their highest notes on the vowel [ʊ].

Finally, Figure 4 shows the treadmill for the high vowels combined with the high pentatonic scale G_4–D_5. There is only one crossing for males. The fundamental f_o crosses the first formant F_1 in the vicinity of the [ɛ] and [e] vowels. The second harmonic $2f_o$ is too high to cross F_1 and too low to cross F_2. The fourth harmonic almost tracks the second formant, note by note. Tuning may occur, but crossings are not clear.

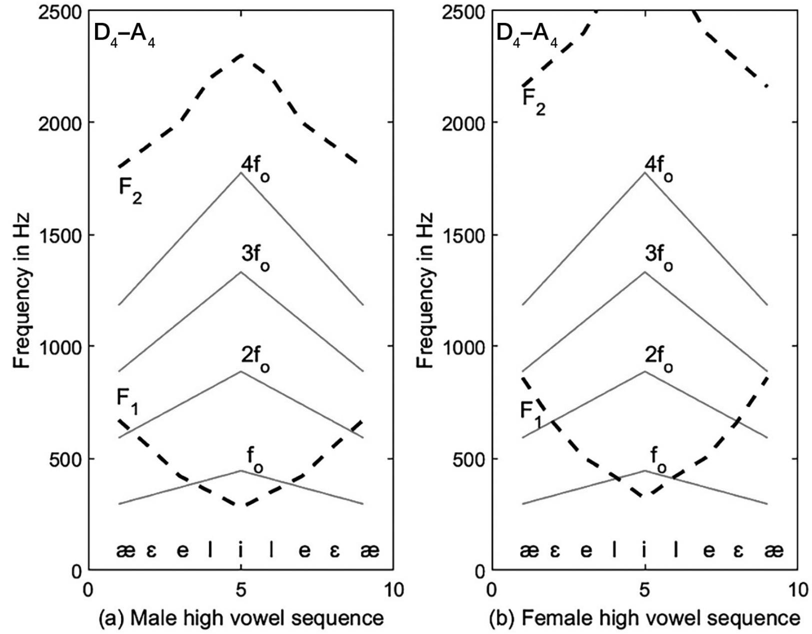

Figure 2. **Treadmill for the D_4–A_4 pentatonic scale produced on high vowels; (a) male sequence and (b) female sequence.**

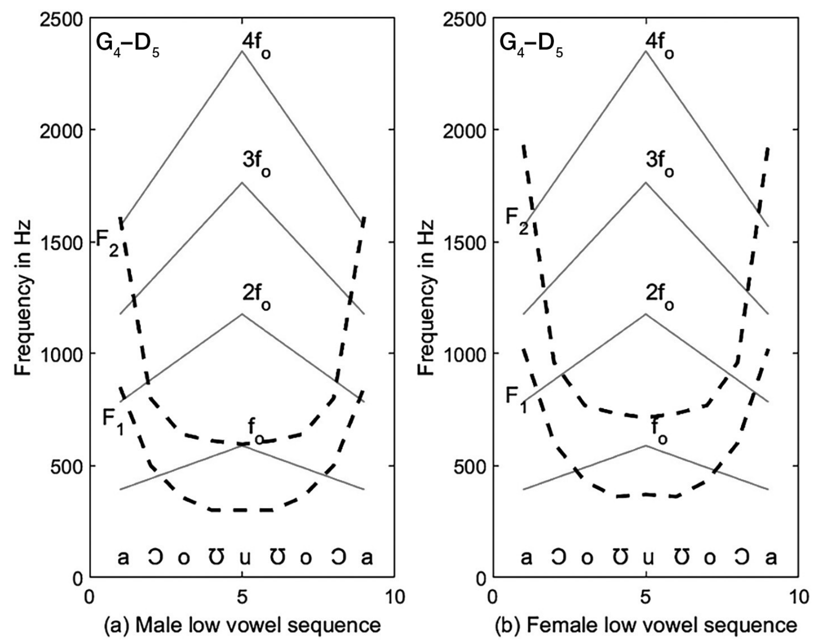

Figure 3. **Treadmill for the G_4–D_5 pentatonic scale produced on low vowels; (a) male sequence and (b) female sequence.**

For females, an important additional crossing can occur with the very bright vowels [æ] and [ɛ]. Here $2f_o$ can cross F_1. The third and fourth harmonic are not near a formant.

In conclusion, readers must be reminded that the vowel formant frequencies chosen here are generic to human anatomy. They are not specific to any individual. Vocalists can measure their own formant frequencies

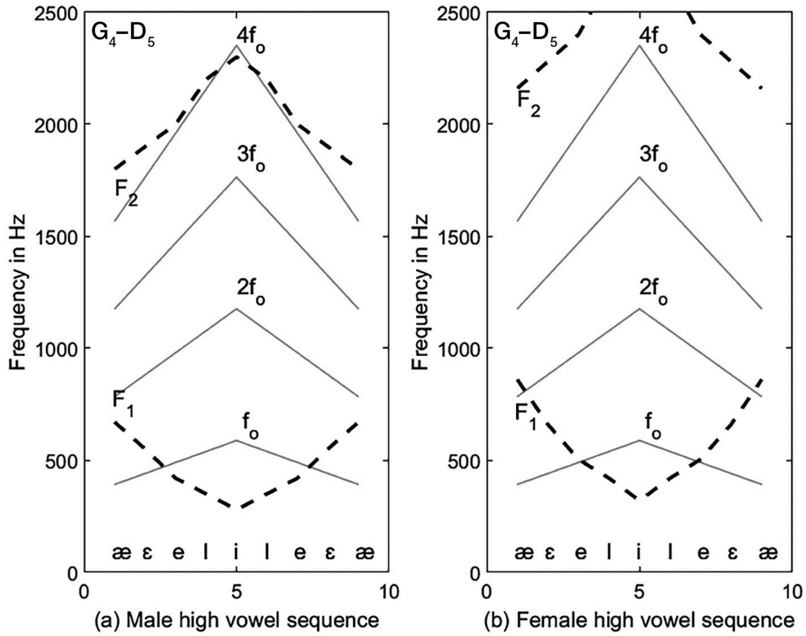

Figure 4. Treadmill for the G_4–D_5 pentatonic scale produced on high vowels; (a) male sequence and (b) female sequence.

and generate a personalized treadmill. It should also be mentioned that vowels are highly modified by singers to prevent these crossovers if they produce voice instabilities. The primary benefit of the treadmill is to explore the instabilities so that they can be smoothed out by training. The motor system for vocalization is then able to adjust vocal fold adduction, laryngeal position, and epilaryngeal airway structure to minimize sudden unwanted registrations. The process is slow, even with daily practice, but eventually a mixed registration will occur without voice breaks or other instabilities. The pentatonic scale can be augmented with other melodic variations in the training process.

NOTES

1. Ingo Titze, "A Pair of Advanced Exercises for Register Equalization," *Journal of Singing* 69, no. 4 (March/April 2013): 447–449.
2. Kenneth Bozeman, *Practical Vocal Acoustics: Pedagogic Applications for Teachers and Singers* (Hillsdale, NY: Pendragon Press, 2013).

Dr. Ingo R. Titze has served as Founder and President of the National Center for Voice and Speech since 1990. His was a University of Iowa Foundation Distinguished Professor of Voice, Speech, and Vocal Music prior to retirement from Iowa in 2019.

He has published over 500 articles in scientific and educational journals. His book publications include *Principles of Voice Production* (1994), *The Myoelastic-Aerodynamic Theory of Phonation* (2006); in collaboration with Katherine Verdolini, *Vocology: The Science and Practice of Voice Habilitation* (2012); and *Fascinations with the Human Voice* (2010), which is printed in eight languages. His research interests include biomechanics of human tissues, acoustic phonetics, speech science, voice disorders, professional voice production, and the computer simulation of voice. His formal training is in Electrical Engineering (MS) and physics (PhD).

Dr. Titze is a founding member and first elected President of the Pan-American Vocology Association. Other professional affiliations include the Acoustical Society of America, The National Association of Teachers of Singing, the American Speech Language Hearing Association, and the American Laryngological Association. Honors include The Gould Award for outstanding research in laryngeal physiology (1984), the Silver Medal Award from the Acoustical Society of America (2007), the Honors of the Association from ASHA (2010), and the Sundberg-Titze Award from the Voice Foundation (2020). He has administered and taught in the Summer Vocology Institute, the premiere Vocology training program, for 20 years. He has been married to Kathy Titze for 52 years, with whom he has four children and nine grandchildren. He remains an active singer.