Effects of HearFones®

1. BACKGROUND

For centuries, singers have intuitively known that cupping a hand to their ear lets them hear themselves better. In ensemble, for example, it's sometimes hard to be sure you're singing on the right pitch.

HearFones were conceived originally to free the hands and to afford feedback symmetrically to both ears, but they've become best known for their spontaneous effect on vocal production. People using HearFones simply sound better. The inventors modestly dubbed this phenomenon "The Miller-Mickelson Effect," knowing no other name by which to call it.

Having learned of HearFones during the 2001 international symposium PEVOC IV in Stockholm, researchers in the Department of Speech Communication and Voice Research at the University of Tampere decided to study this effect -- first to verify and then to quantify how it manifests. The group's results were presented by Dr. Anne-Marie Laukkanen during the Voice Foundation's annual symposium "Care of the Professional Voice" in June of 2002.

Their paper *Effects of HearFones on Speaking and Singing Voice Quality* [1] appears in the *Journal of Voice* -- the official publication of the Philadelphia-based Voice Foundation.

2. INTRODUCTION

In voice and speech training, auditory self-monitoring has been traditionally regarded as highly important. The significance of auditory feedback in the control of phonatory quality can be observed clearly, for example in the case of the hearing impaired. Deviant voice quality is a common characteristic among speakers with severe hearing impairment.

In earlier work, Laukkanen's group reported on the effects of amplified feedback,[2] noting that subjects significantly lowered the pitch and the loudness of their speaking voice when provided with feedback, felt more comfortable, and might develop better speaking habits by finding more economical voice methods from the viewpoint of vocal hygiene. They hypothesized that the subjects' voice production became more relaxed or hypofunctional when provided with audio feedback.

One aspect of auditory self-monitoring in voice training is the simple fact that we don't hear ourselves the same way as other people do. We hear our own voice darkly, because the lower sounds in our voice travel well around and through the head, while the higher sounds are transmitted more directionally from the mouth forward. A simple, effective way to explore this is to plug your ears, first hum and then whisper.

This inability makes it much more difficult to hear any possible breathiness (turbulence in the high-frequency range), raspiness or other acoustic detail in our voices. What others hear, we do not; we're literally "behind" our own sound. To practice eliminating this unwanted noise can build good habits for use later in performance.

Even more important than eliminating noise is to produce the desired sounds. In singing, the vowels are used for extended notes, with consonants usually as transient connectors. Depending on an individual's personal history, each singer brings his or her own dialect of vowels, which may or may not sound well together in close ensemble singing.

Every basic pitch, for example "A-440," is based on its fundamental frequency (440 Hz, or cycles per second). A pure tone at A-440 would be difficult for a human to produce; a boy soprano singing "OO" may be close. But all other vowels make use of "partial" tones at higher harmonic frequencies added to the fundamental. On a graph, a pure tone appears as a sinusoidal smooth wavering. Adding partials puts tighter bends on the shape of this smooth form. The vowel "EE" (as in the Italian "i") is probably the best example of this.

These higher partials have trouble getting to our own ears, but appear at full strength in the listeners'. Again, try plugging your ears and singing "OO-EE" to yourself. Or try it outdoors without plugging your ears.

In voice training tradition, many tricks have been used to give the trainees a better idea of how they sound to the audience. The coach may offer verbal or non-verbal cues which the trainee struggles to interpret into vocal changes; the trainee may be told to sing brighter or darker, or any number of other expressions.

To overcome lack of aural feedback, they might be asked to sing in a corner, or be instructed to bend the pinna forward with the hands, or to cross the arms in front of their face to improve sound reflection back to the ear. Singers have traditionally cupped a hand to their ear, but the unlimited variations in how any one singer might use their hand have generally led voice teachers to discourage ear cupping.[3]

HearFones were developed to serve more comfortably the same purpose as these traditional tricks -- to act as a learning tool. Mounting over the head in just the way as conventional headphones, HearFones use shaped, ellipsoidal sound reflectors -- with one focus at the mouth and the other at the ear -- to carry sound normally directed toward the audience into the user's ears. Their intent is to provide equal-length sound paths to avoid phase distortion -- the sound of talking into a tin can. Developed originally for choral singers, HearFones don't impede the hearing of surrounding sound, and yet they allow free voice production to the audience -- as well as (the inventors claim) an occasional free sip of coffee.

HearFones are fully described in U.S. Patent 6,229,901.

3. SUMMARY OF THE FINDINGS

It might be helpful to summarize the Tampere findings in a somewhat more colloquial format for those who might not work in the formal field of voice research.

This study investigated the effects of HearFones
- on sound perceived by the subject,
- on voice qualities judged while reading and singing,
- on voice qualities during speech and singing at a sustained pitch and sound level, and
- on glottal closure and sub-glottal air pressure at sustained pitch and sound levels.

A. To measure how HearFones affect the sound heard by oneself, text readings were digitally recorded using two identical microphones placed in the ears -- one ear outfitted with HearFones, the other being left normally exposed.

HearFones enhanced sound in the ear across the entire 8 kHz range studied. The greatest enhancements, averaging about 15 decibels, centered around 1-3 kHz and 4-7 kHz -- at or above the soprano range, but covering most significant upper partials and well within the range of normal hearing.

One's first thought might be that sounds in the normal singing range should be the most important, but many details generally considered in singing (timbre, brightness, noise, harshness, breathiness, etc.) lie in this extended range. The upper partials' relative amplitudes are what define the vowels. Moreover, small pitch discrepancies are magnified up to more obvious differences in the upper partials. Indeed, the subjects did comment that they heard their voice louder and brighter and with more audible breathiness.

B. For the effects on voice quality, reading and singing samples were digitally recorded both with and without HearFones. Objective results were recorded and analyzed (for example as spectrographs), and subjective observations were judged by independent professional voice trainers and others listening afterward to the recordings. The listeners judged the speaking voices better in 8 of the 13 speakers, and in 7 of the 12 singers.

The subjects naturally tended to speak or sing more quietly when using their HearFones (HearFones are hardly intended for loud singing) unless they were asked to consciously maintain their loudness level. In judging the voice as better, voice quality was noted as less strained and better controlled while using HearFones than without. Minority judgments of "worse" were based on observations that the voice seemed too weak, too soft or less ringing.

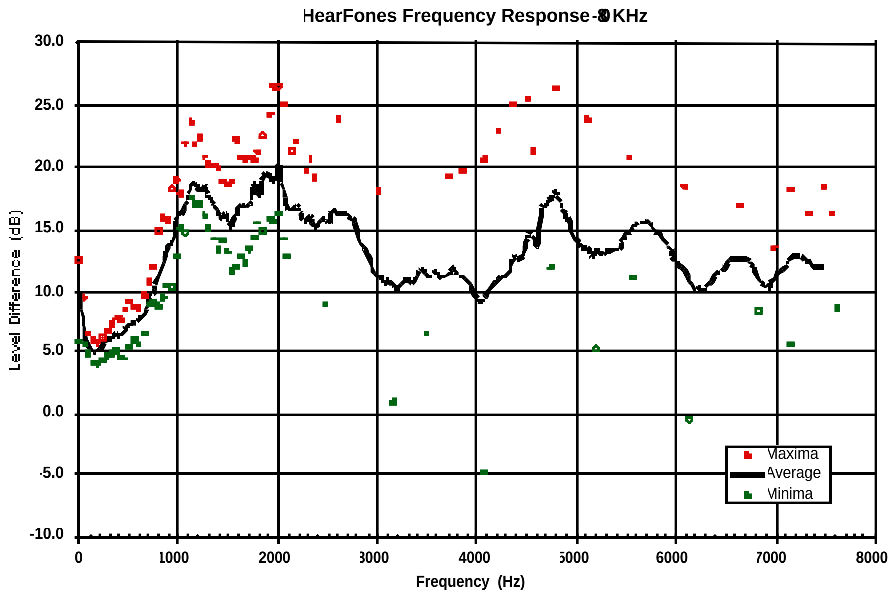
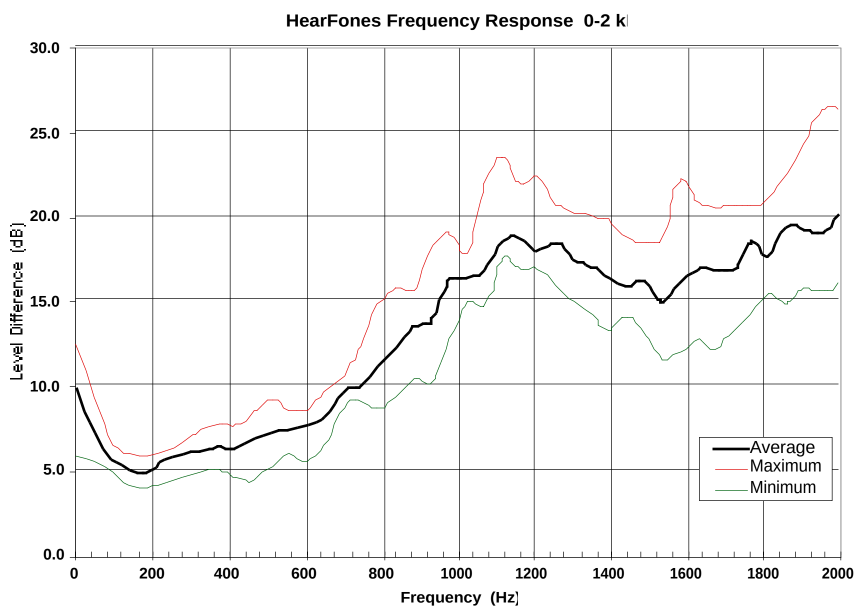


Figure 1

Figure 1 shows the difference in sound level between a normal ear without HearFones and the opposite ear equipped with HearFones. Broadly speaking, across the entire range measured, there's about a 12 decibel gain caused by the HearFones. The subjects hear themselves more loudly by 12 dB, or a factor of about eight times louder. Also shown are colored dots representing the high and low extremes experienced by individuals in the group of four subjects. The values vary more widely as the sound pitch goes up, and these person-to-person variations might be a result of differences in how physiology and mouth shaping affect the sound carried back to their ears. It's interesting to note that – for at least one subject – sounds around 4,000 Hz were quiter with HearFones.

In the singing range, low bass to high soprano (say 50 - 1,500 Hz), Figure 2 shows the same data expanded for more detail. It's evident that HearFones' amplification increases with pitch, from around 6 decibels around C_4 (middle C) to as much as 20 decibels a couple of octaves higher. Clearly there could be an incentive for Papagena to sing lightly when using her HearFones.

Figure 2



There is a well-known “Lombard effect” which predicts that when presented with more sound in their ears, people will speak and sing more loudly, and that louder vocal production correlates to a shallower spectral slope (more noise and more strength in the upper partials), so an added concern of the study was to separate the possibility of an “inverse” Lombard effect (voice with a steeper spectral slope) resulting from simply singing more quietly. To do this, the subjects were asked to sing and speak at the same level, and even in this case the steeper spectral slope was recorded, but to a lesser degree.

This may suggest that using HearFones encouraged the subjects to sing more “cleanly” and thus eliminate some of the noise and harshness that normally shows up as shallow spectral slope. In any case, it could also explain why more observers judged the voice quality on the whole as better or well controlled.

C. To study the effects of HearFones on voice production independently of voice quality, subjects were asked to repeat the nonsense phrase “pa:p:a” (Pa-P-Ah) in both speaking and singing modes, while maintaining the same pitch and sound level.

During the unvoiced consonant “P” interval, when the mouth is closed and airflow stopped, air pressure in the mouth had earlier been shown to correlate with the sub-glottal pressure -- below the vocal folds -- that’s used immediately to sound the openly-voiced “AH” vowel. The degree to which a subject can produce sound at a given sub-glottal pressure is a measure of vocal efficiency, allowing longer phrases and lower vocal stress. A standard measure of vocal health is the threshold pressure at which a particular subject can just begin to phonate at all. In these tests, the subjects’ average pressure was found significantly lower using HearFones.

Simultaneous electroglottograph (EGG) measurements were recorded to examine how the vocal folds opened and closed while producing the vowel “AH.” The EGG is a fairly simple resistance measurement (in ohms) taken between the skin on the right and on the left side of the neck at the glottis. The absolute value in ohms is unimportant, but the comparative value and the rate at which resistance increases (as the folds open apart) and decreases (as they close again) can show delicate detail in how the subject is using their vocal folds.

With pitch and loudness held constant, no statistically significant differences were heard in judged voice quality *per se.* Yet with HearFones the closed quotient (CQ) of the EGG signal was higher (they were closed more of the cycle time than when not using HearFones), the trace was more skewed (the folds opened more gradually and shut more quickly), and the amplitude was found higher in speech (the vocal folds were opened more fully) and lower in singing. The judges’ comments tended to express that the voice with HearFones was produced more carefully.

Both of these suggest a better glottal closure or diminished activity of the thyroarytenoid muscle, and are thus general indicators of more effective and healthy vocal production.

The following sections generally describe the equipment, environment and tests that were used. Again, full details, graphs and statistical reductions are given in the technical document itself.

4. PERCEPTION BY THE SUBJECT AND THE LISTENERS

Environment: well-damped studio
Subjects: 2 male and 2 female speakers
Sound material: spoken text-reading sample (91 words, about 30 seconds)
Recording: TCM-110 tiepin microphone in each ear; digital audiotape (DAT) recorder
Measurements: Long-term average spectrum (LTAS) using Soundswell software

5: VOICE QUALITY JUDGED IN SPEAKING AND SINGING

Environment: well-damped studio
Speech material: text-reading (1 minute); 13 live subjects (9 females, 4 males)
Singing material: folk song (1 minute); 12 live subjects (7 females, 5 males)
Recording: Brüel & Kjær 4120 microphone 40 cm from the mouth; DAT recorder

Acoustic measurements:
- LTAS (excluding all voiceless sounds) using H-P 3561A signal analyzer
- Fundamental frequency (F0) mean, mode and range during text reading
- Sound pressure level (SPL)
- Formant frequencies in all Finnish vowels (a, e, i, o, u, y, æ, ø) using Intelligent Speech Analyzer™ (ISA)

Perceptual evaluations: free-field; DAT; Genelec Biamp loudspeaker using three professional voice trainers
- 1 singing teacher
- 2 speech teachers with singing training

6. VOICE PRODUCTION IN SPEAKING AND SINGING

Equipment

Sound source: 7 female subjects
Sound material: repetition on [pa:p:a], with F0 and SPL kept the same
Acoustic recording: Brüel&Kjær 4120 microphone; DAT
Oral pressure recording: Aerophone II system
Electroglottograph recorder: Glottal Enterprises EGG-2
Measurements: Mean oral pressure; closed quotient (CQ); EGG amplitude (ISA)

7. RESEARCH CONCLUSIONS

HearFones enhanced the sound heard by the subject by 5-20 decibels across the range from 0-8,000 Hertz, with generally less enhancement below 1 kHz and generally more above that, with the result that one's own voice can be heard louder, brighter and breathier (more audible high-frequency turbulence).

The effects of enhanced auditory feedback can be summarized as:
- a steeper spectral slope, indicative of less noise and more cleanly produced sounds;
- improved voice quality, especially for hyperfunctional subjects;
- in some cases, impaired voice quality for hypofunctional subjects;
- involuntarily lower sound pressure level, due to hearing ones self louder.

When sound pressure level and fundamental frequency were deliberately maintained at the same level:
- higher electroglottogram amplitude and closed quotient while speaking.
- lower electroglottogram amplitude and higher closed quotient while singing;
- improved glottal closure.

HearFones may prove useful in speech training, especially for hyperfunctional voice users.

HearFones may help in singing, especially in choral settings where a strong individual voice is not the goal.

8. OTHER CONSIDERATIONS

Beyond the obviously important observations and measurements made in the Tampere research, there are other effects reported anecdotally by HearFones users, some of which are worth following up:
- the psychological and behavioral changes people make when they sing or speak with HearFones;
- the short-term and long-term habits they build, and any benefit those afford;
- whether HearFones' nature of feedback is "relevant" biofeedback or more similar to clinical biofeedback;
- why autistic behavior reportedly changes when using HearFones;
- why excitable lower grade school children calm down when "awarded" with a set of HearFones;
- whether HearFones have any measurable effect on stuttering;
- any other applications where HearFones might prove beneficial.

NOTES:

1. Laukkanen A-M, Mickelson NP, Laitala M, Syrjä T, Salo A, Sihvo M. Effects of HearFones on Speaking and Singing Voice Quality. *Journal of Voice.* December 2004 Vol. 18, Nr. 4; 475-487

Full text, data, graphs and figures are in this reference, available at <www.jvoice.org>, or check your local library. Questions may be directed to Nils Peter Mickelson at <pete@hearfones.com> 207-929-4840, or to Dr. Laukkanen.

2. Jonsdotter V, Laukkanen A-M, Ilomäki I, Roininen H, Alastalo-Borenius M, Vilkman E, Effects of Amplified and Damped Auditory Feedback on Vocal Characterisitics. *Log Phon Vocol* 2001; 26: 76-81

This paper is available at <http://taylorandfrancis.metapress.com/app/home/contribution.asp?wasp=78u409g6wm1uwldcaeet&referrer=parent&backto=issue,4,6;journal,15,29;linkingpublicationresults,1:102099,1>

3. Miller, R. Ear Cupping. *Journal of Singing.* January 2001, pg. 47