Sacrificing Music Quality for Improved Speech Intelligibility in Noise -- It Doesn't Work

Part 1

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18th Annual Canadian Academy of Audiology, (CAA) Conference Niagara Falls, ON October 21 50 years ago (1965), although I had (and still have) normal hearing, I decided to try wearing a pair of BTE hearing aids until I got used to their sound. At first, it was like trying to understand speech in a sea of noise. It took almost six weeks before things sounded normal. Even then, I could still not understand speech in noise as well as I could unaided.

That experience led to a lifelong search for better sound quality in hearing aids, first using earmold acoustics and later by designing circuits

This talk is about what I think I and others have learned since then.



*Fortunately, I had a lot of help from experienced IC circuit designers like Bill Cole, who helped make the K-AMP a true breakthrough.

FIGURE 4. Comprehensive frequency response of each experimental aid, measured using 2-cm⁹ acoustic coupler (60 dB input, maximum gain setting) (from Lawton and Cafarelli, 1978).

Disclosures:

I have a strong financial interest in Etymotic Research, which makes and sells high-fidelity

held otoacoustic emissions test equipment, highfidelity earphones, and high-fidelity Personal Sound Amplifiers, some of which I will discuss.

> I have also taught the advanced Hearing Aid Electroacoustics course at Northwestern University for 33 years.

Further Disclosure: *I like music*



Talks at Indiana University School of Music

I got to play with Jeremy Allen (Double Bass) and Steve Houghton (Percussion)

Here is a 30 second sample of some of the fun, on an old fashioned Boogie Woogie



Greetings from warm and sunny Elk Grove Village, Illinois

Sacrificing Music Quality for Improved Speech Intelligibility in Noise -- It Doesn't Work

OUTLINE

- A. Sacrificing music quality for improved speech intelligibility
 - 1. Historical findings
 - 2. Recent findings
 - 3. Why doesn't it work
- B. What we know about hearing loss
 - 1. Prevention how to hear for a Lifetime [new method]
 - a. If your ears ring afterwards, don't do that!
 - b. If you have TTS afterwards, don't do that!
 - 2. Hearing Loss for loud sounds: Diplacusis, SNR Loss
- C. Doing something about SNR loss
 - some new products that can help –

- Q: Does Sacrificing Music Quality to Obtain Improved Speech Intelligibility in Noise Make any Sense?
 - 1. Experimentally?
 - 2. Theoretically?
- A: It hasn't made sense so far, and probably won't in the future.

All known experimental evidence points to the conclusion that intelligibility in noise, patient satisfaction, and sound fidelity are highly correlated.

The best intelligibility is achieved with the highest fidelity

This is not just my idea. Time and time again over the last 30 years the great researchers in audiology reached that conclusion:

J.Donald HARRIS,

Edith CORLISS & Ed BURNETT,

Jim MILLER & Art NIEMOELLER,

Tom TILLMAN & Wayne OLSON

Dave PASCOE and Margo SKINNER

Dave HAWKINS and Sharmala NIADOO

We will first review some examples recorded over the years, and then consider "why" it probably can't help. In 1960, Edith Corliss and Ed Burnett of the National Bureau of Standards (Now called the NIST) gave a paper expressing concern about the distortion and frequency response of hearing aids.

Ed played a tape recording of three hearing aid examples using cafeteria noise with a radio announcer talking in the background. He included the original sound on the tape.

The following A-B comparisons used his original 1960 recordings of that noisy situation, played first to KEMAR's open ear and then through a 2003 digital hearing aid.



One of Burnett's 1960's analog hearing aids sounded better and gave better intelligibility than this relatively recent "CD Quality" digital hearing aid.

More commonly, we used Live Music for our A-B Fidelity Comparisons

CSO String Quartet Recordings:

- A = KEMAR open ear = reference
- **B** = Hearing aid on KEMAR



Dvorak: American

Comparison 3 The lowest-rated hearing aid (Fidelity score = 20%) Tinny, shrieks



Comparison 5 The highest-rated hearing aid: Fidelity score = 90% (The open ear A-A gave 100%)



ETYMOTIC RESEARCH "CD Quality" Digital Hearing Aid Comparisons

RATING SHEET

RATING SCALE

100% Perfect fidelity (meaning I can't hear any difference between A and B) 90% Excellent fidelity 80% 70% Good 60% 50% Fair 40% 30% Poor 20% 10% Bad 0% Awful (meaning I can't imagine anything worse)

You may use any number you feel best describes the overall fidelity of the aid you heard in a given comparison. A score of 82.3% is allowed, for example, but the standard deviation of such judgments typically exceeds 5%, so rounding your rating to the nearest 5% probably makes sense.

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Practice 1	
Practice 2	
Practice 3	
Comparison 1	
Comparison 2	
Comparison 3	
Comparison 4	
Comparison 5	
Comparison 6	
Comparison 7	
Comparison 8	
Comparison 9	
Comparison 10	
Comparison 11	
Comparison 12	
Comparison 13	

Bates

Results of previous A-B Fidelity ratings

(Names of 2003 digital aids with ratings below 40 are withheld to protect the guilty)

Hearing Aid	%Fidelity Rating	Comments
W	40	Missing highs
Analog K-Amp	80	Good
X	20	Tinny, shrieks
Open Ear A-A	100	Perfect, no difference
DigiK	90	Near perfect
Widex Senso	70	OK, bit harsh
EZ-5	45	Weak highs
Y	35	Awful, shrieks
Open Ear A-A'	85	Near perfect
Siemens Triand	<u>40</u>	Thin, bit harsh
Siemens Prism	a 65	Mid freq's bit strident
Sonic Innovatio	ns 80	Good
Phonak Claro	85	Good, bit excess highs
	Hearing Aid W Analog K-Amp X Open Ear A-A DigiK Widex Senso EZ-5 Y Open Ear A-A' Siemens Triand Siemens Prism Sonic Innovatio Phonak Claro	Hearing Aid%Fidelity RatingW40Analog K-Amp80X20Open Ear A-A100DigiK90Widex Senso70EZ-545Y35Open Ear A-A'85Siemens Triano40Siemens Prisma65Sonic Innovations80Phonak Claro85

ANOTHER EXAMPLE: A LIVE RECORDING OF A HEARING AID WIDELY ADVERTISED AS "CD QUALITY" IN 2002

A-B COMPARISON:

A = KEMAR OPEN EAR B = "CD QUALITY" #1

(DVD with video of each of the A-B comparisons available on request)



A THIRD EXAMPLE: ANOTHER 2002 HEARING AID WIDELY ADVERTISED AS "CD QUALITY"



(DVD with video of each of the A-B comparisons available on request)



Q: Did the sacrifice of music quality in those digital aids improve speech intelligibility in noise?

A: No. Just the opposite!

Intelligibility goes down as music quality is sacrificed



This was true for both sloping-loss and flat-loss subjects



The astonishing result is that there is nearly a perfect correlation between a) the hearing aids' ability to deliver high intelligibility in noise and b) the fidelity ratings on live music of *normal-hearing subjects*.

Can you have too *much* digital noise reduction?

Absolutely. Your Cell Phone is an extreme example. It uses (excessive) digital noise reduction to:

- a. cover up the noisy cellphone transmission and
- b. allow more users on the same cell tower transmitters

Since music can be clearly distinguished from speech, it is easy to destroy.

"Precious Lord, Take my hand" through Motorola cell phone







Many of the state-of-the-art "CD Quality" hearing aids purchased in 2002 were not suitable for use by a musician

(Hearing Review 2004 "Myths" papers)

How about premium best-in-class hearing aids purchased late in 2008?

(I was hoping to find hearing aids beside the K-AMP and DigiK designs that you could recommend to musicians)

RECORDING SESSION at ETYMOTIC RESEARCH Inc. Classroom Studio December 4, 2008

Recordings of state-of-the-art hearing aids purchased in 2008

KEMAR THE PIANO PLAYER

	Once in a While	-
Open E	ar Hea	ring Aid "D"
	3 Notes	-
Open	Ear Hea	aring Aid "D"
	Blues	-
Good	QSA He	aring Aid "D"

Each live A-B comparison was obtained from the sound simultaneously recorded in the left and right ears of the KEM AR® manikin. In most cases, the left ear (B) had a digital hearing aid in place, while the right ear (A) ear was open or had an analog hearing aid (K) in place





Open Ear

Hearing Aid "D"

One hearing aid sounds reasonably clean



Even Really Good Violinist warm up!

(I <u>didn't</u> warm up before the next example)



Alwayswarm up!



Good QSA Hearing Aid "D"

Example from another of the latest premium hearing aids, Hearing Aid "E"





I would not recommend these \$6,000/pair hearing aids to anyone who likes music.

Two final examples using the live KEMAR recordings from the CSO String Quartet, reproduced over a high-fidelity loudspeaker



Both hearing aids were factory set for a 40 dB flat loss.



Boogie

Open Ear -- New Digital Aid "Q"

Each live A-B comparison was obtained from the sound simultaneously recorded in the left and right ears of the KEM AR® manikin. In most cases, the left ear (B) had a digital hearing aid in place, while the right ear (A) ear was open or had an analog hearing aid (K) in place





Open Ear -- New Digital Aid "Q"

(2008 picture, 2011 recording)

So far we have talked mostly about digital frequency-response distortion and time-constant distortion.

There is another age old distortion that can dramatically interfere with music quality and, of course, speech intelligibility.

Input-Stage Clipping Overload

Hawkins and Naidoo (1993) noticed that many of their binaurally-fitted patients at Mayo Clinic reported that they understood better in a party or loud restaurant **if they used only one aid** <u>even though they had **tested better with two aids** in the sound booth.</u>

They discovered the reason: Their aids distorted so badly in loud noise that they took one off. Hawkins & Naidoo confirmed this with much louder speech & babble in the sound booth. Some aids started clipping just above normal the level of normal speech!



Note: A cocktail party typically measures 80-95 dBA SPL, with corresponding peaks of 90-105 dB SPL

What levels are required for music?

As a listener, on three occasions I have clocked the Chicago Symphony Orchestra at 104 dB SPL on a Sound Level Meter, which corresponds to 114 dB SPL peaks – In the balcony.

I've had a few music lessons and I myself can produce 112 dBA SPL at my ears singing or playing a trumpet.

Professionals are in a different class. I have clocked Charlie Menghini, president of VanderCook College of Music and a virtuoso trumpet player, at 119 dB at his ears. I clocked a soprano opera student at Northwestern University at an astonishing 123 dB at her own ears. Sometime back I collected several live measurements, String Quartet from Chicago Symphony, etc. The result was the paper and graph below.

What Special Properties Do Performing Musicians Require? Killion (2009)



In the following, we compare those required levels with the hearing aid ability.



Six recent Digital hearing aids (Jensen, 2013)



So what have musicians been using?



Jessen (2013) reference table with bandwidth included

Maximum input is defined by a rapid rise in 3rd harmonic = clipping ((from Jessen, 2013).

Max on 312	Hearing aid A	Hearing aid B	Hearing aid C	Hearing aid D	Hearing aid E	Hearing aid F	
INPUT HANDLING	INPUTAGC	INPUTAGC	INPUT CLIPPING		INPUT CLIPPING	INPUT CLIPPING	The BEAN Input Clippping
MAX. INPUT	92 dB SPL	95 dB SPL	102 dB SPL	108 dB SPL	103 dB SPL	113 dB SPL	115 dB SPL
SAMPLING FREQUENCY (MAX BANDWIDTH)	- (10 kHz)	- (7.9 kHz)	- (7.6 kHz)	- (7.6 kHz)	33.1kHz (10.4 kHz)	33.1kHz (11 kHz)	(16 kHz)
BITDEPTH					16 bit	16 bit	Analog; (18 bit equivalent)

Multi-channel dynamic compression: Concepts and results

Inga Holube, Volkmar Hamacher, Matthias Wesselkamp Siemens Audiologische Technik, Erlangen, Germany Birgitta Gabriel Hörzentrum Oldenburg, Germany 1990 Arrowhead Conference

Influence of release time on the temporal structure of speech



LISTEN AGAIN TO THIS FAST "SYLLABIC COMPRESSION" EXAMPLE WE PLAYED BEFORE (WIDELY ADVERTISED AS "CD QUALITY" IN 2002)

A = KEMAR OPEN EAR B = "CD QUALITY" #1



Spectral Smearing

Vowel-formant peaks can be brought down so near the vowel-formant valleys that the classic vowel series

heed hid had hod hawed hood who'd

Can come out as the neutral Schaw vowel "uh"

In the following Holube data, the spectrum of complete sentences was presented, but even there it is obvious that something is missing in the 16-channel spectrum

Influence of Compression on spectral smearing



Fig. 2: Influence of number of compression channels on the spectrum of a speech segment. The upper left panel shows the original signal.

Influence of Compression on spectral smearing



Fig. 2: Influence of number of compression channels on the spectrum of a speech segment. The upper left panel shows the original signal.

The subjects of Holube et al. made hundreds of comparison judgments.

The result was clear: Independent-channel compression with multiple channels and short time constants was generally detested by both normal-hearing and hearing impaired subjects.

Results for normal-hearing listeners



Results for hearing-impaired listeners



Q. Does that mean that multi-channel compression can't be made to work well?

A. No, of course not. The DigiK was a four-channel digital system that showed the highest fidelity ratings and the highest intelligibility in noise of any digital hearing aid tested.

(Even better than the analog K-AMP.)

But it does mean that it takes a much more sophisticated handling of compression than has sometimes been done in the past.

And one thing never changes: It is **always** a good thing to listen to the hearing aid itself **and to the patient** as well. More sound examples, recorded this year during a study on directionality among Big 6 hearing aids.

INVESTIGATION ON THE INFLUENCE OF EARMOLD SEAL ON EFFECTIVE HEARING AID DIRECTIVITY

Northwestern University **Capstone Project** STACIE BEEGLE AND ERIN KELLEY July 2015





All recorded with sealed earmolds



Rel. SNR 0 dB

2.8 dB (Better)

-0.2 dB (Worse)

Can audiologists (or engineers) listen to a hearing aid and predict how someone with hearing loss will rate it?



Hearing impaired listeners tend to rate distortion and fidelity about the same as those with normal hearing as long as it is well above threshold. (Also Gabrielsson et al. 1976)

How about perceived (Dollar) value?

Palmer (1988) found a tight correlation between dollar-value ratings and quality. Her hearing-impaired listeners rated each Quality percentage point as worth \$6.75 using the instructions that "Hearing aids cost as much as \$700 each. How much would you pay for a hearing aid that sounded like this?"

That would correspond to \$48 per Quality percentage point using a more modern cost of \$5000 a pair.

In our study, we told our subject to assume hearing aids cost \$5000 per pair.

Surprisingly enough, our subjects also rated the dollar values nearly the same (at \$50 per fidelity percentage point!)

DOLLAR RATINGS: HEARING AID WEARERS VS NORMAL HEARING SUBJECTS

DOLLAR VALUE RATINGS COMPARISON HI (N=6) VS NH (N=17), JAZZ PIANO TRIO



DOLLAR RATINGS: HEARING AID WEARERS VS NORMAL HEARING SUBJECTS

DOLLAR VALUE RATINGS COMPARISON HI (N=6) VS NH (N=17), JAZZ PIANO TRIO



Hearing impaired subjects appear less willing to pay for low fidelity sound, Perhaps because they know they will have to wear the aids.

How do you find high fidelity hearing aids? Easy: All you need to do is wear them and LISTEN to tell which is which.

Musician's quick predictive evaluation:

Piano sounds: Even a scale is useful, augmented with chords Violin double stops high on E string Singing and speaking loudly (as in a noisy cocktail party)

But the real tests are:

Wear them in the real world

Localization OK? (it should be)

Naturalness (forget that old "It's supposed to sound bad.")

Forget all that. Listen to music aided and unaided in your car while driving – or while parked with the motor running and the air conditioning turned on. Classic, Jazz, the also the announcer's clarity.

Ask "Would I pay \$5,000 for hearing aids that sounded like that?"

(If you chose well, the answer might be "Yes!")

A 2003 DVD containing audio-video recordings of KEMAR listening unaided (open-ear) and aided (seven "state-of-the art" digital hearing aids) to musicians from the Chicago Symphony Orchestra can be obtained from Etymotic Research by emailing

customer-service@etymotic.com

Ask for the "DigiK DVD"

A recent Karl Strom interview of me with audio examples included can be found at www.hearingreview.org