**Understanding the Problem**

Headphone frequency response measurements are not only difficult to make, but also quite difficult to interpret. Headphones can't be measured with normal measurement microphones, they have to be measured like they are used—coupled to a microphone that mimics the acoustic characteristics of the ear. Essentially, when we measure a headphone, we are taking a measurement of what the ear drum hears.

The problem is, by the time outside sound gets to your ear drum it's not flat any more. Our brain is used to hearing sound with this non-flat ear drum response. When we measure headphones we have to know very precisely what that non-flat ear drum response is so that it can be subtracted from headphone measurements to return them to a flat line for evaluation. In order to understand headphone measurements, you have to understand the various factors considered to develop this headphone target response compensation curve. You'll also have to understand that an industry-wide standardized curve currently doesn't exist (though one is in development), so there is no clear answer regarding "what flat is" with headphones. With this article I hope to provide you with a few helpful concepts and hints, but plenty of questions will remain at the end.

This article will be in two parts. This first part, will explore the target response curve and how to recognize it. The second article will look at specific types of artifacts seen in headphone frequency response measurements, and what they mean.

**What our ear drum hears in front of a speaker.**

At the top of the diagram above, we see a measurement microphone in front of a speaker. Let's assume it's a perfectly flat speaker being measured in an anechoic chamber (a room with no acoustic reflections). The microphone will have a very small interaction with the acoustic...
energy, but for the most part it is designed to measure very accurately the sound field present without disturbing it. In this case, if the speaker is "flat" (acoustically neutral), the output from the mic will also be flat.

Now, let's remove the mic and put a person in front of the same speaker and look at the signal at that person's ear drum. It will no longer be flat because of a number of acoustic interactions between various parts of the body with the incoming acoustic signal. The graph below shows the various acoustic gain contributors to the frequency shaping heard by a person positioned in front of a speaker.

![Graph showing various acoustic gain contributors to the frequency shaping heard by a person positioned in front of a speaker.](http://www.innerfidelity.com/content/headphone-measurements-explained-frequency-response-part-one#ILPLzZrDG4Uhsq6T.97)

The dotted black line (1) shows the boundary gain from your head. Assume for a moment your head is roughly a one foot sphere. At very low frequencies, with half wavelengths much longer than the dimension of your head, there will be little interaction between the acoustic wave and your head. But as you raise the frequency of the sound to the point where its half-wavelength is of similar dimension as the head, you begin impede the sound and create some gain at the boundary. In the case of a 12" head and the speed of sound at 1126 feet/sec, sound will start getting some gain at around 563Hz. As you can see, the plot of spherical head gain is at 0dB below 300Hz, and then slowly transitions to about +3dB at around 1200Hz. (To the best of my understanding, boundary gain at the side of the head should only be able to deliver 3dB of increase, while the chart shows around 6dB at 10kHz. Sorry, I can't explain why this is so.)

Likewise, your torso (shoulders, chest, belly) will provide some boundary gain. Your body is bigger than your head, so its effect will begin at lower frequencies. But because your ears are not directly attached to your body and are separated at a distance, as soon as the half-wavelength becomes equal to that distance you will begin to lose coupling and the effect will diminish. You can see that dashed line (2) in the chart above indicating the torso providing some gain at lower frequencies to about 1kHz. Between 1kHz and 2kHz this torso curve actually goes negative due to destructive interference between the direct sound at the ear and the sound being reflected off the torso. Above 2kHz there is no torso interaction capable of significantly shaping the sound heard.

Colored lines in the graph above represent acoustic gain contributions from various parts of the ear itself. The blue line represents the focusing effect of the concha bowl into the ear canal of sound in the mid-treble region (with a peak at about 5kHz). The green line represents contributions from the pinna flange, which are somewhat lower in frequency due to being farther from the ear canal opening than the concha, and lower in level due to the milder cup shape of this area of the ear. The ear canal and ear drum resonance is represented by the red line (5), and shows its first resonant peak at about 3kHz (1/4 wavelength of ~1" long ear canal). If you were to extend this line further you would also see resonances at about 9kHz (3/4 wavelength resonance) and 15kHz (5/4 wavelength resonance).

Finally, we can sum all these gain contributions together to get a full picture of the differences between what a measurement mic hears in free space and what your ear drum hears when you place your body in front of a speaker. The solid black line labeled "Ear Resonance" shows the sum total acoustic response present at the ear drum. Another way to think about it is the acoustic transfer function of the ear, head, and torso. Because our brain is used to hearing with this response, it sounds flat to us. When we measure headphones at the ear drum, we are not looking for a flat response, rather, we are looking for a response similar to the curve in the
Unfortunately, there are some significant problems figuring out the exact HTRC to use.

Individual Variations
Most obvious is that all these specific response curves are generated by a specific geometry in the shape and size of a person and their specific ear shape. The particular graph used above is probably an average of many people, but the fact remains that your specific body, head, and ear shape will likely produce a different response curve at the ear. The Head Acoustics head I use for headphone measurements has an ear specified by international standards (IEC 60318-7:2011) to be exactly average for all humans, but it too will differ from your ear response.

So, this is the first thing to know about headphone measurements: They were not made with ears the same size as yours, so the sound you hear may objectively be somewhat different than the measured values. There really isn't much that can be done about this. For the sake of accuracy and relative consistency some one human looking ear needs to be used for all measurements, it seems to me the use of a standardized average ear is a good option. I wouldn't say the magnitude of this problem is huge—after all we're all listening through human ears that do have significant commonalities—but I do think the differences could be enough for the same headphone to sound audibly different (mostly in the treble area above 2kHz) on two different people.

Sound Source Direction and Acoustic Environment
This is where things get very complicated (as if it hasn't been complicated enough already). In the above "Acoustic Gain Components" graph we've been using so far, you'll notice at the top left that this graph is for sound coming from a 45 degree angle. I'm pretty sure this graph was also done with a flat speaker in an anechoic chamber. If you change the angle of the speaker relative to the head, the geometry of the torso, head, and ear changes relative to the acoustic wavefront, which will in turn change the acoustic resonances and the associated peaks in response.

Also, if you take a speaker that measures flat in an anechoic chamber and put it in a normal size room with typical acoustic characteristics, it will sound (and measure) somewhat warmer as the room's volume reinforces bass notes (usually below 200Hz), and the speakers radiated power into the room decreases as they get more directional at high frequencies (results in approximately 3dB tilt between 200Hz and 20kHz).

To summarize: the target response curve at the ear drum will change significantly as you change assumptions about the direction of the sound source and the acoustics of the room you're in.

Historical Target Response Curves
The world of audio engineering has historically had only two standardized ear drum response curves: Free-Field (FF), and Diffuse-Field (DF). The FF curve was the population averaged measured response at the ear drum for sound coming from directly in front of the listener in an anechoic chamber. The DF curve is the population averaged measured response at the ear drum for sound coming from all directions simultaneously in a very reverberant (hard-walled) environment.

The graphs above are simplified versions of the compensation curves for the Head Acoustics HMSII measurement head I use. You can see these curves are similar, but upside down, relative to the ear drum response curve we've been looking at. That's because these are compensating curves intending to reverse out the ear drum response and bring it back to flat.
28/4/2016

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The Independant of Direction curve is one invented by the company and is not an internationally adopted standard. It is essentially a DF curve with some of the head and torso effects taken out of the calculation. It is the compensating curve I use for InnerFidelity graphs.

Historically, the DF curve had been generally adopted as superior to the FF curve as a target response curve for headphones. But over time, and largely due to discrepancies between the objectively derived DF curve and other subjectively developed target response curves, headphone makers have been moving away from the DF curve as their target response for headphones.

What makes sense as a target response curve?
I've been trying to make good headphone measurements for about twenty years now. I've given this subject a lot of thought, and the answer has always seemed simple and obvious to me: If music is mixed and produced to be played back on speakers, and if good headphones are suppose to sound the same as good speakers with recorded music, then the target response curve should be the ear drum response of a human head and torso in front of two ideal speakers in an ideal acoustically treated room of about living room size. In simpler terms, I've always thought that good headphones should sound like good speakers. It just makes sense.

The approach then would be to put a measurement mic in front of two very good speakers in a very good room and take a baseline measurement. Then place a measurement head in the same position and take the ear drum measurement. Then subtract the baseline room measurement from the ear drum measurement and you've got a new target response.

Unfortunately, that is a lot easier to say than to do. To make that measurement very well there are a number subtle nuances to the measurement (like spatially averaging the response over a range of listening angles) and very expensive equipment and well trained operators are needed. This is an expensive undertaking to do well, so there had better be a darn good reason to go to the effort. My internal hunch is probably not a good enough reason.

Fortunately, I'm not the only person to have this hunch.

Harman Target Response Curve in Development
I won't go into too much detail in this article as I've written extensively about it here, here, and here, but researchers at Harman International lead by Dr. Sean Olive have been working diligently for the last couple of years on defining a new headphone target response curve.

Their very thorough research has lead them to the basic conclusion that headphones should sound like good speakers in a good room.

The graph above shows the ear drum response as measured on a dummy head at the normal listening position between a pair of speakers. The green dashed line shows the ear drum response for a speaker that has been equalized flat at the listening position. The black line shows the adjustment away from flat while wearing headphones that most people chose as more pleasing.

There are a couple of nuances to understand here. First, most speakers are designed to measure flat in an anechoic chamber. When a speaker is put into a room it gets a bass boost from the proximity of the walls—this boost typically happens at about 200Hz and below. It also naturally gains a warm tilt due to the ever reducing sound power being put into the room as the frequency gets higher and the speakers directivity becomes more narrow.

The important thing to take away from this is that the goal is not actually for flat sound in the room. The goal is actually for the slightly warmer sound of speakers designed to be flat in an anechoic chamber and how they interact with the room. One of the underlying suppositions here is that we humans know what a room does to sound, and we accept—in fact, expect—that the sound from a good speaker will change in the room.
Another interesting subtlety in the research was that while the ear drum target response curves for speakers and headphones were quite similar, people actually preferred slightly bass and treble on headphones than they do on speakers (about 2dB on either end).

**Headphone Frequency Response Measurements**

And now, finally, we can talk about what to look for in a headphone frequency response measurement. All of InnerFidelity’s headphone measurements can be downloaded as .pdf files for viewing. You can download them one at a time from the list on this page, or you can download them all in a single AllGraphs.pdf document. (CAUTION! AllGraphs.pdf is over 50MB and growing, so it will take a while to download.)

The top left graph on each of the measurement pages is the frequency response plot. You’ll see two sets of response plots on this graph. The bottom set is the raw measured ear drum response of the headphone. I make this measurement five times and slightly move the headphones each time. All ten (five left and five right) are shown. The reason for doing this is that the measurement will change as various resonances change as the position of the ear within the headphone moves to different positions. By taking five measurements I can average them all together and remove some of these changing resonance artifacts. This is called spacial filtering.

The top plot is the averaged raw responses compensated by the Independent of Direction compensating curve that came with my measurement head. Over time I’ve come to look much more at the raw, uncompensated curves than the compensated plot, primarily because I know the ID (or DF or FF) compensation curves are not quite correct.

When I look at the frequency response plots above with an eye towards understanding its tonal balance, I am primarily looking at the raw response plots and mentally comparing them to what I understand of the Harman Target Response. The NAD VISO HP50 above is quite close, as is the Focal Spirit Professional.
In the image above, I’ve crudely superimposed the raw FR plots of the NAD VISO HP50 (top gray lines) and Focal Spirit Professional (bottom gray lines) on the chart showing the preliminary Harman target response curve (black line). These two headphones are among the most neutral I’ve heard, and they do match the Harman target response quite well relative to other headphones I’ve measured.

One thing you’ll notice with both these headphones is that the rise into the bass starts at about 400Hz, while the rise into the bass on the Harman response starts at about 200Hz. This causes the bass to mids transition to be a little too thick or overly warm sounding, and is quite common with many headphones.

Someday, I will convert my compensation curve to something like the Harman target response, until then just have to use your imagination and keep the preliminary Harman curve in mind as you look at the raw plots. I’ve created this image to give you some numbers to remember as you evaluate the raw frequency response plots.

I’ll also point you to this article where I select a number of well known headphones and apply an estimation of the Harman response curve. Personally I think it may have a tad too much bass, the peak at 3kHz may be a few dB too high and may need to slide up to 3.5kHz, and the area above 10kHz may be too rolled off.

We’ll get into some of the specific characteristics to look out for in headphone measurements in part 2 of this article, but it’s important to note early on that high frequency measurements are dominated by the wild swings of the resonant behavior of headphones. When you look at the profile of the frequency response curve at the high frequencies, you need to mentally average out all the peaks and dips to an average level to get a good feel for what’s really there.

**A Side Note About Other Headphone Measurement Systems**

In the current article, I’ve been quite insistent on the importance of industry wide headphone measurement standards and instrumentation. It is of crucial importance that standards become adopted as it allows industry participants to operate on an apples-to-apples basis, and it allows for more efficient further progress in areas of research. The problem with this gear is that it’s exquisitely expensive. Last time I checked, artificial heads like mine were around $25k by the time you got all the options properly sorted; and the simpler couplers were in the $7k region. Accuracy is expensive.
Above left is the Head Acoustics HMSII head and torso simulator used to measure headphones here at InnerFidelity. Above right is the B&K 4153 artificial ear simulator. Both instruments comply with international standards and will deliver substantially similar measurements when measuring the same headphones.

However, if you've read the above article carefully, you'll see that even with extraordinarily expensive equipment, accuracy is hard to come by. For many hobbyists who simply want to keep objective track of headphone modifications or want to do some basic headphone comparisons, home made headphone measurement systems are possible. A couple are mentioned in this article. I think this is an absolutely terrific hobbyist activity. (I didn't have a lot of time to research it, so I would love it if any InnerFidelity readers who have made their own measurement systems and written about them post links to your gear in the comments. Thanks!)

But it's important to recognize a few things about those measurements vs. the measurements from industry standard compliant instrumentation. Some hobbyist systems are designed to approach industry standard compliance, but many are not and aren't attempting to. Measurements taken on these various systems of a particular headphone model may be substantially different and should be considered apples-to-oranges comparisons. The only time you can even begin to compare headphone measurements from different systems is when industry standard compliance couplers are used. Even then, different operators will place the headphones on the couplers a little differently yielding varying results. Some manufacturers prefer to make measurements that will be presented to the public on the Neumann K100, a head shaped microphone that makes roughly flat response measurements for roughly flat headphones, but not compliant with headphone measurement standards.

The point is, all the advice in this article is only true when you're looking at headphone measurements taken with standards compliant instrumentation. And, if you're going to compare headphone measurements, always compare measurements that have been made on the same system. It's also helpful if you are going to look at any set of measurements to get used to the way that particular lab's measurements appear. To really get the feel for this stuff you have to spend a lot of time listening to headphones while you're looking at graphs. There's some good learning available there...but beware, there's also ample opportunity to create your own little rabbit hole of expectation bias.

On the other hand, measurements are the one thing you can look at with a sense that some truth is there to be had. Measurements are real...how meaningful they are isn't easy to answer, but we'll keep plugging away at it.

Here's Part Two of this article.

Resources
InnerFidelity AllGraphs.pdf and measurement data sheet page.
InnerFidelity articles on the Harman Target Response Curve here, here, and here.
Other articles on headphone measurements on Stereophile, Soundstage, Rin Choi's Blog, and Golden Ears.
Ultrasound's (Rin Choi) Head-Fi Listing of all sites providing headphone measurements, which, unfortunately, doesn't include a link to Marv's measurements at the very bottom of Changstar's home page or the weight of information in their measurement forum area.
Jude Mansilla (Head-Fi Founder) comments on headphone measurement systems.

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http://www.innerfidelity.com/content/headphone-measurements-explained-frequency-response-part-one#ILPLzZrDG4Uhsq6T.97
Phew!
Submitted by tony on February 6, 2015 - 7:15pm

I just tried to read this discussion, twice.

I hope there isn't gonna be a test in the morning.

Can I just follow the "Wall of Fame" recommendations?, I'm starting to get a headache.

My own ears have an "unknown" frequency response curve, the headphones have a "known" frequency response curve! Can I discover a good set of settings to match to?, if so I could then just insert a dbx 31 band Eq. into the circuit to flatten out everything.

Thanks for trying to edjamakate us.

Tony in Michigan

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I love this stuff!
Submitted by Seth195208 on February 6, 2015 - 8:28pm

Thank you! Just outstanding!

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My measurement gear
Submitted by Rillion on February 6, 2015 - 11:45pm

My measurement gear consists of in-ear microphones, my head, and a measurement microphone (to make calibration curves for the in-ear microphones). There are obvious advantages to this vs a dummy head. A not-obvious disadvantage is that microphone cable rubbing is a serious nuisance when measuring closed-back sealed headphones. On the other hand, it also shows quite clearly that breathing and heartbeat can be amplified to ridiculous levels with sealed headphones. Of my 5 sealed headphones only the budget-friendly TASCAM TH-MX2 does not have this issue.

Anyway, back to the gear. I use two in-ear microphones: one for 800 Hz and below, the other for 800 Hz and above. The lower frequencies are better reproduced by "The Sound Professionals" MS-TFB-2 shown here: http://www.soundprofessionals.com/cgi-bin/gold/item/MS-TFB-2

which sits just outside and to the side of the ear canal. For the higher frequency range, I use 4 mm diameter microphones that I ordered from Digikei and had to solder wires to myself. The wires came from an old Sony Walkman headphone. After potting the connections, the microphones were then glued to some foam ear plugs that are trimmed down to slightly less than half their normal length so that the microphone is nearly flush with the entrance to the ear-canal. Inserting them is not easy -- I use a 3-pane vanity mirror that allows me to see the side of my head and ear-canal opening. I use a small alligator clip to grip the perimeter of the microphone to help insert it. This morning I added some additional protection to the wires so that I can use the insertion tool (small tube) that came with my Alpine reusable ear-plugs instead of the alligator clip (haven't tested this revision yet).

The in-ear microphones are powered through a TASCAM DR-5 linear PCM recorder.

The measurement microphone is a Dayton Audio EMM-6 (comes with a calibration curve). I am powering it with a Rolls MP13 Mic Preamp.

Here are the components and Part Numbers that I ordered from Digikei:
433-1107-ND Microphones
CW2500-ND Epoxy Overcoat
ST 7-ND Soldering Iron Tip

The glue used was Pliobond 25 from Ace Hardware. This is nasty smelling and carcinogenic but only a tiny amount is needed to securely attach the (electrically potted) microphone to the foam tip.

I enjoyed listening with the equalizations I discovered but frankly taking the measurements and processing the data was a pain in the A** since I do not have an automated system. Being handy with Perl has helped, but there are
Still a lot of steps. Software: Audacity, SoX, spreadsheet.

Thanks, great post!
Submitted by Tyll Hertsens on February 7, 2015 - 8:37am

Thanks for a really interesting post, Rillion.

"A not-obvious disadvantage is that microphone cable rubbing is a serious nuisance when measuring closed-back sealed headphones. On the other hand, it also shows quite clearly that breathing and heartbeat can be amplified to ridiculous levels with sealed headphones."

The amount of mechanical noise with some headphone is indeed surprisingly high. I mentioned it in my Master and Dynamic MH40. One thing I've noticed is that many noise canceling headphones, by their nature, cancel this mechanical noise. So, when I'm outside in the winter wearing a coat with a hood, the noise canceling headphones can be a lot better listening experience than plain sealed headphones as they make noise rubbing against the hood.

Thanks for the detailed info on your system. Are you primarily using it to EQ headphones? Do you modify headphones?

Yes, primarily for EQ
Submitted by Rillion on February 7, 2015 - 10:25am

In reply to Tyll's question. Yes, I use it primarily for EQ. I've dabbled with some easy headphone modifications like adding damping material between driver and earpad or trying different earpads. Replacing the Senn. HD518 felt earpads with velour ones improves comfort and gives about a 2dB boost in the sub-bass (not really audible for me). Adding damping material to AKG702 or Phiaton PS320 didn't improve the sound enough by ear for me to keep the changes.

Bose
Submitted by Rillion on February 8, 2015 - 10:07pm

I've been considering buying the QC25 or QC20 since I read your thorough and well written review of them. I finally pulled the trigger on the QC25 this afternoon. I am very pleased with this purchase. They are even comfortable while wearing glasses (which is something I wish you would address more often in your reviews). I always enjoy your articles. Keep up the good work!

EQ for QC25
Submitted by Rillion on February 19, 2015 - 1:29pm

I know this thread is becoming old now, but I thought it might be useful to add some of my findings concerning the Bose QC25. Considering the wiggles in its frequency response in the treble I was surprised at how good it sounded by ear. In my music samples the only place I found it come up slightly short was in reproducing cymbals—they sounded a bit muted (compared to my "ideal" target response). The two dips located with my in-ear microphones that made the most difference in music listening tests were at 2470 Hz and 4640 Hz. If you have access to a parametric equalizer (such as in Rockbox or Neutron player), these can be corrected with the following settings:

Band 1: freq = 2470 Hz, Q = 4.4 (octave bandwidth = 0.33), Gain = 7 dB

Band 2: freq = 4640 Hz, Q = 5.5 (octave bandwidth = 0.26), Gain = 5 dB

The values in parentheses are for use by Neutron whereas Rockbox uses Q. Depending on your equalizer, you may also want to apply a
Precut to prevent clipping. The ideal values of the parameters listed will likely differ with different heads/ears, but at least this can serve as a starting point.

I emphasize that these are subtle changes but they can be heard by listing to brief sections of music containing drum-kit cymbals. Happy listening!

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**It was the drums instead.**  
Submitted by Rillion on February 19, 2015 - 11:51pm

At the risk of embarrassing myself, it was the drums themselves and not the cymbals where the difference was audible. The cymbals sound pretty much the same without the correction.

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**One simple question**  
Submitted by markus on February 7, 2015 - 2:00am

When I listen to sinus tones with headphones, the loudest frequency should be somewhere between 3 & 3.5 kHz and that area should sound 10-12 dB louder than 220 Hz, right?

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**No.**  
Submitted by Tyll Hertsens on February 7, 2015 - 8:57am

No. Theoretically, even though the signal is physically louder, our brain is so accustom to this response curve that it hears it as flat. If you are doing sine sweeps to set EQ, you should adjust EQ so everything sounds the same level.

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**These curves are the latest equal loudness charts.**  
Submitted by abel on February 7, 2015 - 10:06pm

Here:

https://www.google.com/search?q=iso+226%3A2003&rlz=1CAACAG_enUS574US574&es...

I just googled ISO 226:2003 for this image, supposed to be the latest version.

As you may know, these curves were from tons of subjective trials from all around the world that had people adjust the apparent loudness of tones compared to a set level at 1khz. They used headphones for this test. Hmmm, How did they calibrate those cans?

You can see from your headphone measurements that the SPLs at the ear drum (not at the entrance to the ear canal) are similar to the inverse of the equal loudness curve at about 80 dB. This is close to how the SPLs at ear drum would be with a flat sounding headphone. Of course, that doesn't mean that the headphone produces a peak at 3kHz, it is flat in power output when you measure this peak at the ear drum. Our sensitivity to sound, especially low level sounds, is greatest due to the ear's resonances and the cochlear cilia's responses at that area of the frequency spectrum. That is probably the best for good survival, be it for hunting, or preventing being hunted. All makes sense if you hope to pass those genes on.

Wonder what volume levels you use for your frequency charts Tyll? Isn't it best to equalize all charting to 0dB at say 1Khz so as to not introduce variance due to SPL? Probably better than supplying the same power to cans with such varied sensitivity, and charting the results. To compare the sound of transducers, be it speakers or cans, isn't it essential to match output levels at a reference frequency? Do you know what the Canadian researchers do to keep SPL the same in their tests? Knowing the equal loudness curves, and knowing...
that most music is mixed on recordings at fairly loud levels, so that it sounds best when played back at higher levels that listeners use when really listening for maximum connection to the music, it seems likely that testing and measuring would be done at that level.

I'm glad you keep on doing these measurements! I too, have been looking more at the raw data on your charts. Someday, the flat sounding cans you measure will have a fairly flat line frequency graph. It will be good when that finally agreed upon curve can be applied to your data! It is in the numbers that you have, but will be expressed much more usefully. The Newman head users have taken a short cut to this end.

The thing you have to understand is that the Fletcher-Munson equal loudness contour curves are subjective in nature. Basically, the lower the volume the more you have to boost bass and treble to be perceived as sounding balanced.

But measurement systems are not perceptual and will respond exactly the same (Measured curve will have the same overall shape) regardless of level. So, for measurement purposes, there is no need to even think about FM curves.

Again, FM curves are perceptual and subjectively measured, and not objectively "real".

...when arriving at a target curve such as the Olive group's, measuring loudspeakers in room response with microphones at eardrum location in a dummy head yields a sort of inverse curve of the FM curves, due to the HRTF of the dummy head. Then they adapted that curve subjectively to better match the perceived frequency response of the cans to the speakers. Just speaking of the target curve that was arrived upon by that method, wouldn't the loudness of the speakers influence the target curve based on the FM curves? Knowing that the FM curves are not at all the same for speakers and headphones (the latest curves were done with loudspeakers I think) then it would make sense to have the target curve match the speakers at a given SPL, and one that is at a "universal" listening level. I just thought it was interesting to note how the FM curves relate to actual measured SPLs at the eardrum.

This is a wonderful 'once over' look into really complicated stuff. Moar Food For Thought...

Another important sources for (IMHO) valid measurements are:
1) PersonalAudio.ru (http://personalaudio.ru/raa/otchety/naushniki/)
2) KO.GoldenEars (http://ko.goldenears.net/board/GR_Headphones)

Also, I have personally started doing headphone measurements on our audiophile website (http://headaudio.weebly.com/). It's not in English but all the graphs are... Anybody can use them as a source as well if interested. For any commentary in English language, just contact us or use Google translator -)

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Additional comment
Submitted by JE on February 7, 2015 - 7:28am

Just to add, I personally wrote an article dealing with our headphone measurements… So if anybody is interested in them, this article is the best one to start with: http://headaudio.weebly.com/informacie/zavadime-sluchatkova-mereni

Also, I forgot to thank Tyll for the article!

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You're welcome, and thank you!
Submitted by Tyll Hertsens on February 7, 2015 - 9:01am

You're welcome, and thank you! It's important that folks who can help educate others. Knowledgable listeners make for demanding customers, which in turn encourages manufacturers to build better headphones to remain competitive.

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Thanks for this post.
Submitted by jebel on February 7, 2015 - 10:24pm

I have these as some new bookmarks on my computer, thank you.

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What about differences between each individual's two ears?
Submitted by Smiling Kev on February 7, 2015 - 7:28am

Great piece of work, Tylll! In the process of all the measuring and data massaging to achieve some sort of useful standardized response curve, is there any provision for accounting for the fact that lots of us have substantial anatomical, neurological and acuity differences between our left and right ears? Or do those differences not really make a substantive difference, since each person’s brain automatically combines the two divergent channels of sensory information while constructing perceptions of the source’s signal? I'm not trying to make things more complicated, Just wondering the impact on all of this the fact that my right ear and left ear come close to measuring as if they were from two different species, not just two different people! Thanks again for the article - I'm really looking forward to Part 2.

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Well, yes.
Submitted by JE on February 7, 2015 - 8:49am

Difference between your left and right ear can be significant => possible to detect even when listening to stereo music with your headphones. It's of course possible to measure this difference (for example with a help of your audiologist). It could theoretically distract you if you are really focused on spotting the difference but your brain is going to adjust for this phenomenon during normal listening sessions.
As you suspect...
Submitted by Tyll Hertsens on February 7, 2015 - 9:08am

"Or do those differences not really make a substantive difference, since each person's brain automatically combines the two divergent channels of sensory information while constructing perceptions of the source's signal?"
My understanding is that it's not that the signals get combined but that we just mentally adjust for the response at each ear. As an aside, I did get my diffuse field ear drum response measurement made for each ear individually at Etymotic. They said my ear canals were about average in their response, and there were frequencies at which the difference between the two canals was as much as 5dB. The techs said that was about normal as well.

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Fletcher Munson
Submitted by zobel on February 7, 2015 - 4:24pm

The equal loudness curves of Fletcher Munson looks a lot like the inverse of the correction curves. How well do these actually relate?
Thanks for the review of frequency testing for headphones!
I know there are other aspects to the sound that can be even more important to perceived quality, and your distortion and impulse and square wave charts, and channel to channel comparisons are welcome too. Also, thanks for the impedance and sensitivity information also vital.

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The latest curves...
Submitted by zobel on February 10, 2015 - 12:12am

The new equal loudness curves have replaced two previous standards:
http://www.lindos.co.uk/cgi-bin/FlexiData.cgi?SOURCE=Articles&VIEW=full&...

This is a cool image showing the effects of music at too high SPL:
https://www.google.com/search?q=iso+226:2003&rlz=1CAACAG_enUS574US574&es...

Here is something we should keep in mind:
http://www.sengpielaudio.com/PermissibleExposureTime.htm
See the stuff there on IEMs in particular?
Happy listening!

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How is the measurement of each part of the ear..
Submitted by Seth195208 on February 7, 2015 - 11:23am

..taken in isolation of the other parts, when in in reality, they are never in isolation. They can only interact with each other, and never can they not react with each other. Just curious.

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Scientists with slide rules..
Submitted by Tyll Hertsens on February 7, 2015 - 12:00pm

Scientists with slide rules...or something like that. My guess is that it's calculated from models and inferred from measurements of peoples ears.

Also, you can pack a little clay in parts of the ear and see how things change. In fact, doing that to your own ears is educational...sounds start coming from the wrong direction.

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I've often wondered if the
Submitted by Agyns on February 7, 2015 - 1:44pm
I've often wondered if the generational gap between older listeners who grew up mostly on speakers, and younger listeners (like me) who have primarily listened on headphones, somehow plays into tuning headphones. What I mean is that, up through recent years, most decent headphones have aimed for DF-like tuning. And an entire generation of listeners grew up with headphones tuned like that, just the same way as the previous generation of listeners grew up with the "good speakers in a good room" ideal.

Is it possible that, while wholly appropriate for the "speaker generation," the Harman curve might not be the best solution for those who seldom experienced music outside of headphones made in the past twenty years or so?

Case in point, I tried the NAD HP50 recently. Comfort issues aside (bloody skull crushers, them!), I just couldn't quite get on with the sound. It was impressive from a technical standpoint, but the tuning just left me cold. Not like my DT880, which, while bright (sometimes to a fault on sibilance-prone material), just sounds far more "correct" to me. The DT880 is a DF-tuned headphone (Beyer even confirms this somewhere on their website, IIRC), whereas the HP50 is a lot closer to the Harman target curve. I can extrapolate from this experience that I most likely won't like any headphone with that tuning. I'll keep an open mind, of course, but it seems like the HP50 captures the essence of this tuning, and my issues with it seem fundamental.

I'm not suggesting that the Harman curve is worthless (far from it!). Having choice, and working to better understand how humans hear headphones, can only be a positive. But in much the same way as the "good speakers, good room" logic seems intuitive for those who look to that scenario as their benchmark for good sound, it seems to me that a more DF-like tuning is equally appropriate for those who grew up listening to equipment that almost exclusively targeted said curve.

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Does Age Influence Headphone Sound Preferences?
Submitted by Tonmeister on February 11, 2015 - 12:07pm
We recently investigated whether headphone sound preferences were influenced by age, listening experience and culture. We tested 238 listeners from Canada, USA, China and Germany ranging in age from 20 years to over 55. We found no significant effect in headphone sound preferences related to any of those factors. see http://seanolive.blogspot.com/2014/10/at-recent-137th-convention-of-audi...

Cheers
Sean Olive
Director Acoustic Research, Harman
Past President, Audio Engineering Society

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Really good reading
Submitted by ednaz on February 8, 2015 - 9:17am
You keep doing things like this you're going to have to buy a bigger motorcycle helmet.

Ever since I learned about ears, eardrums, and hearing as a kid, I've wondered whether the world sounded different to people with ears like our current President has versus those of Lyndon Johnson versus my own. I did some experiments once with changing things on my own ear, not with clay but with sound absorption material like cotton or foam rubber. It made a noticeable difference but then I got caught up in "so what" and concluded that while everyone probably hears the world differently none of us can really know HOW. And then I moved on to being interested in girls.

After reading all this, it seems to me that building a generally great sounding CIEM might be a less complex task than having to think about trying to nail a middle ground through the morass of ear differences. I know that some headphones that people rave about sound not great to me, particularly over ear closed design, and others that I think sound fantastic are often scoffed at.
by the aficionados. I find my opinions are less different on open design headphones, and pretty much consistent with those of other critical listeners for IEMs and CIEMs. Hmm.

Unfortunately for my family, I’m going to go try the modeling clay experiment, with a couple of my favorite headphones, and with speakers in my listening room. Creating another "weird dad" family gathering story, but this article got me thinking...

You really do have a gift for explaining complex concepts, and I like where you sketch out where there’s some varying opinions. I’m going to dive back in for a third read later today, after a few experiments.

Which is correct?
Submitted by skris88 on February 14, 2015 - 9:30pm

I used a pair of Sennheiser HD-424s for a decade, judging all loudspeaker systems by the tone of the 424s.

When I was handed a pair of Sennheiser HD-600s I was shocked at the "dull sound". It was only when I learnt they were a Reference Standard of sorts that I forced myself to accept their balance, but always weary of a slight mid-bass bump - and, once I found that same bump on a frequency response plot (in Stereophile magazine review I think) was happy to take 2dB off with an equaliser and settled myself in to simply enjoying the music.

These days I'm much more acutely aware that there also exist thin, boomy, shrill or dull recordings, so I've learnt to respect this Reference Standard.

But the learning here is that our brain can be fooled to prefer a false balance, and can be re-trained when required.

The question then is, what is THE Reference Standard in this new century?

By the way, I've tested the 'accuracy' of the Sennheiser HD-600 balance by simply playing a track I know not to be unbalanced in it's recordings to a non-audophile listener. Their reactions to headphones other than the HD-600s usually are so-so (I've spent a lot of money and have 10s of headphones from various manufacturers). But their reaction to the HD-600 balance with the same recording is always incredulous. I'll never forget one response, "She's HERE standing my head!"

It's gotta be Real. Only correctly balanced headphones can do that.

Hopefully these tests etc help use define a curve to help buyers avoid the majority dud 'phones out there, and there ARE some incredibly cheap AND good ones out there.

How would "flat" headphones sound?
Submitted by ab_ba on February 15, 2015 - 8:01am

Tyll, I've searched for information just like this on the web, but I never found anything this informative. Thank you for it! I learned three things I'm really glad to know:

1) Headphone design has a fundamentally different objective from speaker design. Speakers are designed to have a flat frequency response; Headphones are not designed to be flat. They're designed to compensate for the fact the sound source is so close to the eardrum, so that it will be perceived as flat, given that the sound can't be colored by your head and ears. And, nobody can say (yet) exactly what that compensation curve should look like. On the face of it, this makes headphone design a "much" harder problem than speaker design - there's no "right answer". I hadn't really landed on that fact before this article.

2) We are going to be getting better and better and better headphones for years to come.

3) I should spend more time at changstar.com.

And, I've got three questions:

1) How about this approach: Design the headphones to be flat. Measure your
own head-related transfer function, sitting in your favorite listening room. Play
your music filtered through that, just like any other equalizer. You could even
get a binaural effect by eq'ing each ear separately.

2) What would “flat” headphones sound like? Are there any headphones out
there that have been engineered to be flat?

3) Tyll, I hope sometime in the near future you talk us through the other plots
in your measurements. I know you’ve done that before, but it’d be great to
have it updated, and at this level detail. In particular, the step-response
measurements.

Thank you!