Headphone Essentials 5:

Wrapping your head around the whole flat/neutral/Harman thing

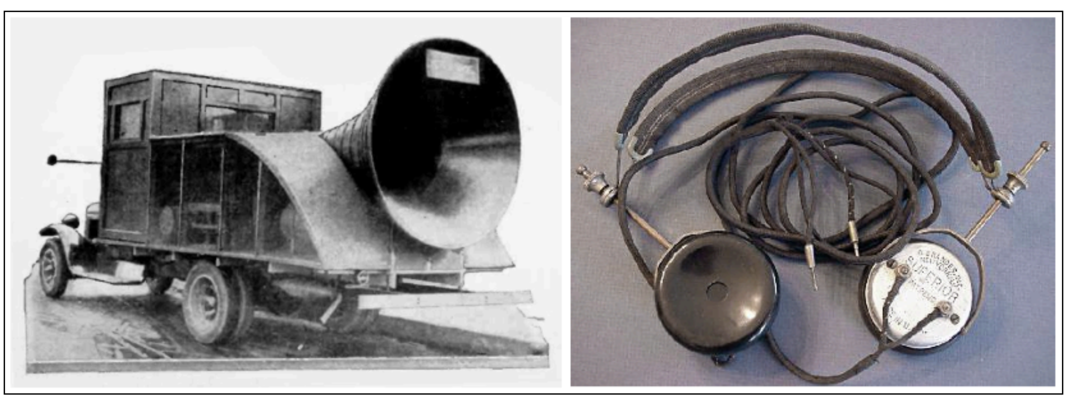
Note: this document is part of a instructional series. If you would like to start with more foundational information on the nature of sound and related material, see *Basics of Musical Sound*, *Basics of Headphone Sound* and *The Skinny on Headphone Frequency Response Graphs* at Headphone Essentials.

Note: this document is about establishing baselines, not about telling anyone what to enjoy.

This document focuses on the frequency response or tuning of over-ear and on-ear headphones. In-ears have a related but different frequency response regime. This document is a summary and synthesis of available research and was written by a headphone enthusiast for other headphone enthusiasts. My aim is to present the material in a readable, relatively non-technical manner. Thus inevitably, I gloss over many complexities. This analysis and interpretation of the available research is purely my own. I provide references to easily available source material so you can form your own opinions. That this document is in its fourth major revision in three years reflects how much my own understanding has evolved with continuing research.

The search for accuracy

If you go to the store to buy a light bulb, chances are you're looking for one that produces white light. Red, purple, blue, green, etc. make for fun and games. But for boring old practicality it's hard to beat white. White light is a mixture of all other hues except black. White light is also the colour of sunlight during the greater part of the day. Illuminating things with daylight white light maximally reveals the colours of objects from apples to zebras. This happens because our eyes and brains evolved to make it so.



Left: horn loudspeaker truck, 1929, first commercial headphone, Brandes Superior Matched Tone, circa 1919-21. Photo credits: left: C. Sterling Gleason, right: John Davidson, License

Roughly the same situation exists in audio reproduction, except here we're dealing with sound instead of light. Testing consistently demonstrates that loudspeakers with a flat frequency response when in an echo-free environment are still the most accurate option for sound reproduction in a reverberant environment, such as a room or concert hall. Flat, in this context, means that the sound coming out of the speaker at all frequencies or pitches from deepest bass to shrillest treble is the same loudness as the electrical signal going in, like so:

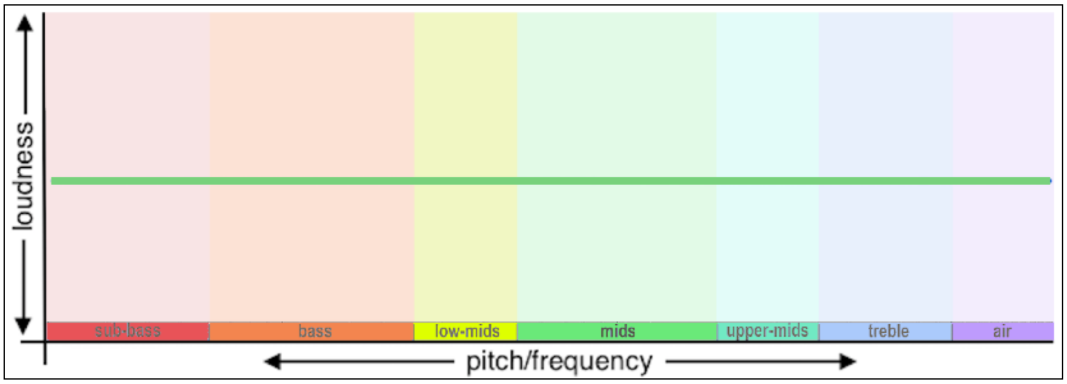


Fig. 1: flat frequency response

In Fig. 1 I've use the colour spectrum to suggest the spectrum of sound from bass to treble. To get a better feel what this means you may want to go to the **Online Tone Generator**. Make sure the volume on your computer is initially set to a fairly low level, then press the space bar once to turn sound on, then move the slider fairly slowly and evenly left and right. If the sound changes in pitch but not in loudness you're hearing a flat response. If it gets louder and softer as you move the slider, that's a non-flat response. If possible, try this with more than one headphone or speaker to see how they vary (remembering to start at a low loudness level with each one). As is typical, the speaker built into my laptop doesn't produce any sound at all to the left of 100 Hz.

Fig. 1 is how an ideal loudspeaker should measure. But by the time the sound reaches our eardrums that same straight-line flat actually measures something like this:

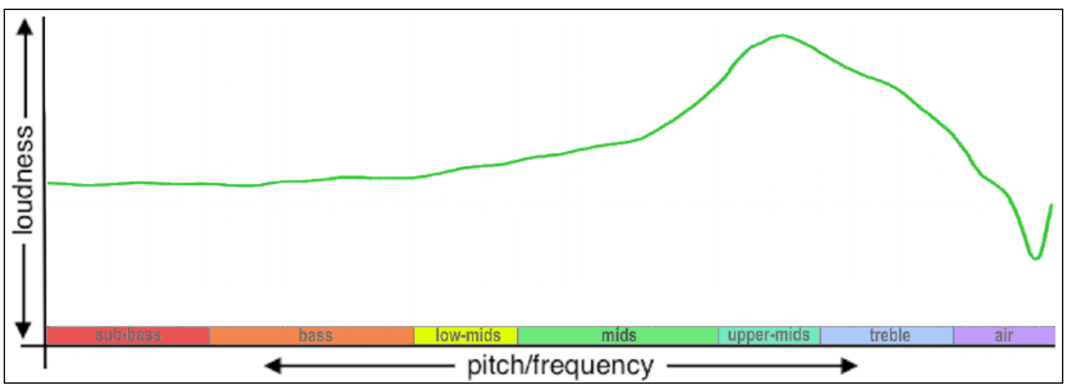


Fig. 2: flat speakers measured at the eardrum (GRAS 45 equipment, source: InnerFidelity article, Fig.5)

The huge (15 decibel) rise in loudness of the higher frequencies on the right is due to a combination of the shapes of our upper bodies, heads, outer ears and ear canals selectively amplifying some frequencies and reducing others. The shape of our ears was designed by evolution, presumably to boost our hearing in an area that was critical for survival. But our brains also evolved to process that enhanced sound in a way that retains the extra information while reducing its perceived loudness back to the Fig. 1 flat line again before we have conscious experience of it. This signal processing magic happens behind the scenes and in real time. We don't hear the boost we just hear the extra details.

There is, however, a complication. When sound is produced in a room, the sound output reflects off the room's walls and other surfaces. The result somewhat emphasizes lower frequencies over higher frequencies. This is called *room gain*. It is this modified version of flat that our ears expect when listening to most recordings. There is no one version of this — even mix and mastering studio acoustics are notoriously all over the map — but the general idea is:

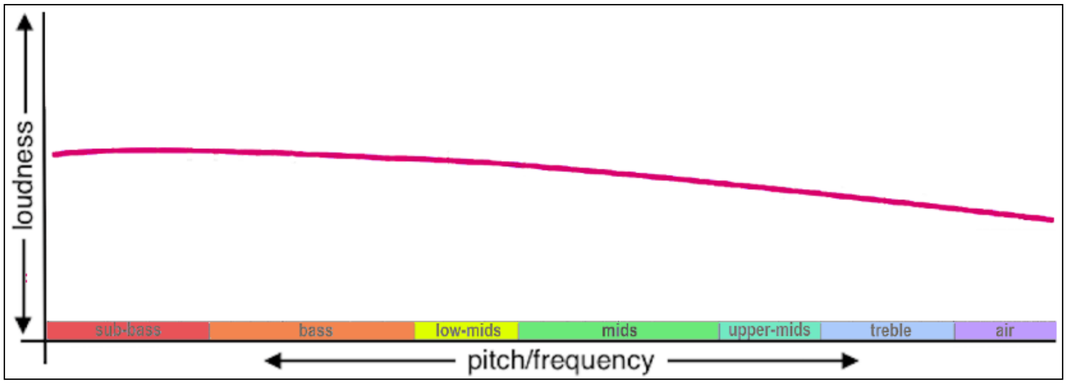


Fig. 3: room gain frequency response (B&K Optimum HiFi)

The curve in Fig. 3 is the result of a study by acoustic research firm Bruel & Kjaer of what an ideal room response should be. This is a balance between the acoustics of concert halls with that of smaller venues. But of course any given room in any given house will have wildly varying acoustics. Loudspeaker enthusiasts spend lots of time and money trying to tame the most egregious faults of their listening rooms. Since recordings are at least traditionally engineered to sound properly in a typical room of a house with typical stereo speakers in it, the sound measured at the eardrum will be a fusion of the two inputs — speaker output plus room gain:

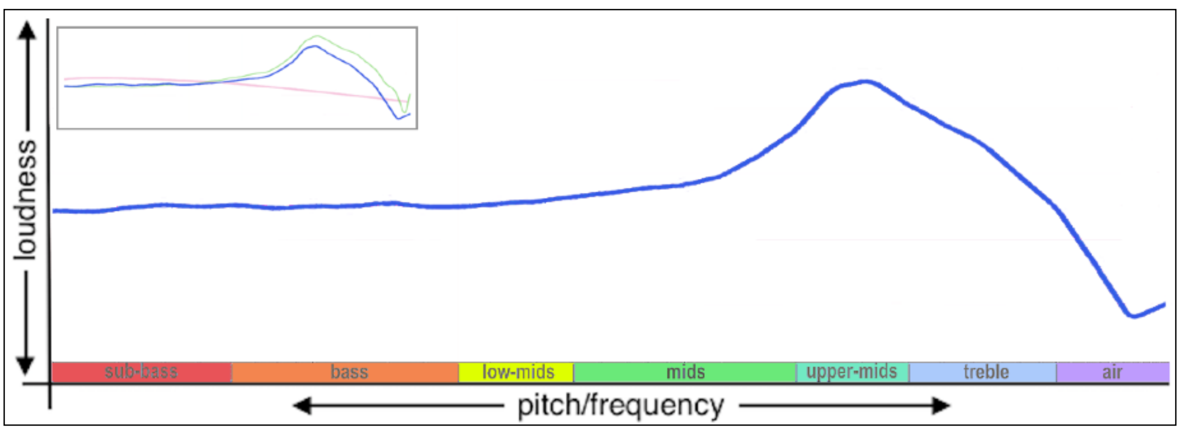


Fig. 4: Combined Harman loudspeaker measurement + B&K room gain

The result is a kinder, gentler version of the unmodified speaker's output. The highs are significantly tamed over those of the loudspeaker on its own (11½ decibels, down from 15 decibels).

> Let's make sure we have all this clear before moving on: Fig. 4 is what happens when a flat-measuring loudspeaker (Fig. 2) produces sound in an ideally reverberant room (measuring like Fig. 3). Then the resulting sound is picked up by a statistically average pair of human eardrums situated inside statistically average, anatomically correct human ears.

We care about the eardrum response because a headphone is typically joined flush to the wearer's head leaving no place outside the headphone's ear cups for it to be measured from. This means that measurements can only be made either by inserting a small microphone into the gap between the wearer's ear and the headphone or by re-creating the acoustic characteristics of the human ear at the ear drum with some mechanism. This latter approach is the one that is used as the IEC industry standard. The result is that we have no equivalent of the simple Fig. 1 graph for headphones, so we have to work with the irregular eardrum graphs such as Figs. 2 and 4.

Fig. 4 is based on the only publicly available industry standard eardrum measurements of a flat loudspeaker I know of. However, the acoustic engineer known online as Oratory1990 has applied the same logic of marrying the B&K room gain curve to an even more refined loudspeaker/eardrum measurement to produce a very similar, but more accurate, curve:

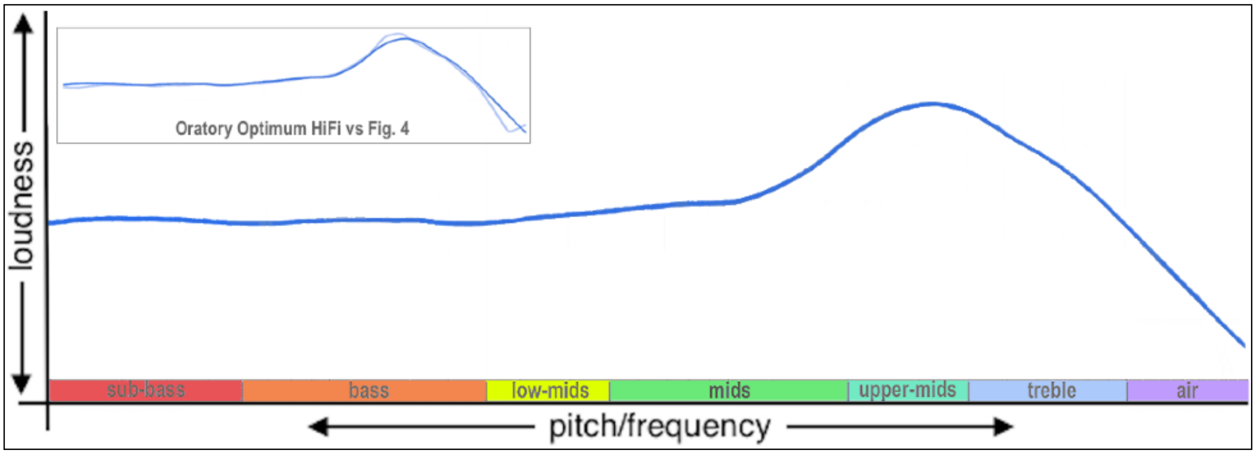


Fig. 5: Oratory1990 Optimum Hifi headphone reference curve (source: headphonesdatabase.com)

Headphone enthusiasts love to sneer at the Harman target curve that we see in Fig. 6:

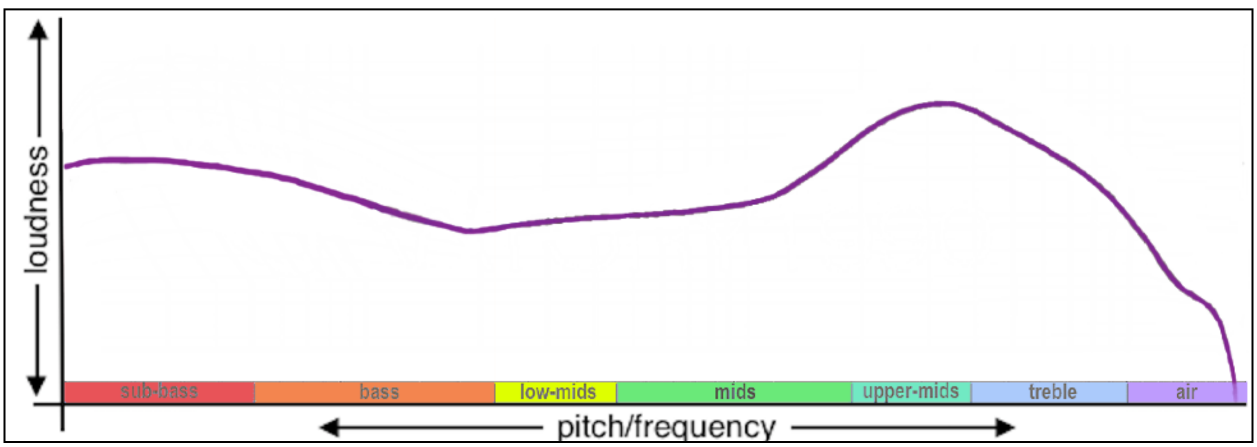


Fig. 6: Harman 2018 over-ear/on-ear headphone target curve

And indeed, I too find the huge swelling on the left an affront to all things beautiful and good. But the problem isn't the curve itself. Rather it's the fact that the **Harman research** was touted as being a neutrality reference target during its developmental years from 2013 to 2018. The initial version had a *somewhat* more stomach-able 4 decibel bass boost. But when the current form started to take shape a few years later, much of the headphone enthusiast community was appalled. The meme soon arose that it was dismissible as *mere* consumer preference research and not to be taken seriously by those with discerning perceptions.

The Fig. 6 loudness curve was arrived at by having some 250 listeners across a variety of demographics manipulate a bass and a treble dial while listening to a selection of representative contemporary popular music via headphones. The bass and treble dials adjusted the tonal balance of the sound they were hearing to match their dial changes. Fig. 6 shows the averaged result of all their choices. We'll examine this a bit more below. Right now I want to point out how this compares to Oratory1990's curve in Fig. 5:

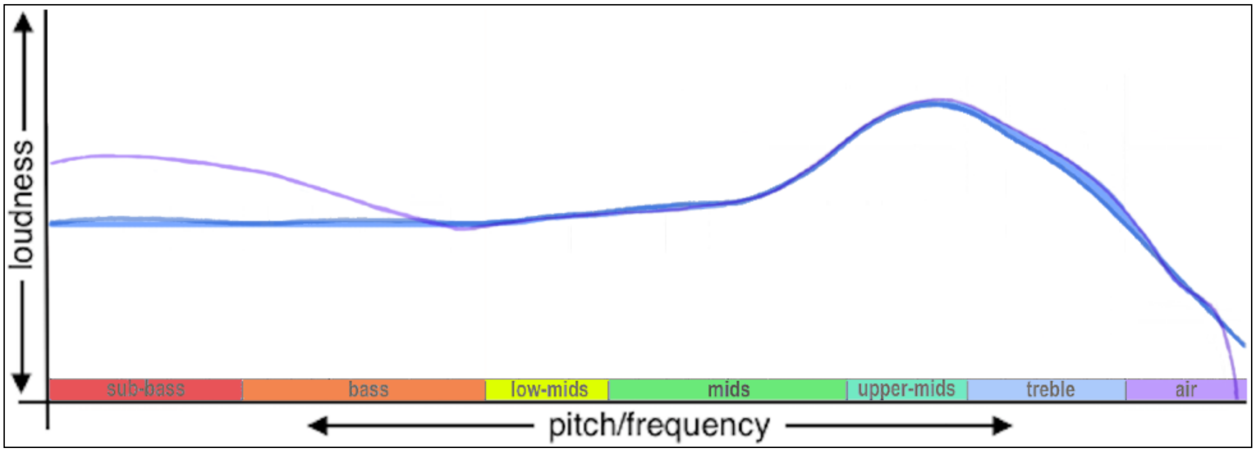


Fig. 7: Harman 2018 target compared to Oratory Optimum HiFi (source: Jaakko Pasanen/AutoEQ)

The match to the right of the big bulge in the bass area is uncanny. But what about that major divergence on the left? It turns out the tested listeners had a huge range of bass preferences with the one we see in Figs. 6 and 7 being simply the overall average.

HORN: to simplify further discussion I'm going to refer to the flat-bass curve with the mid-range and highs in the narrow band of overlap that we see in Fig. 7 as the great **Harman-Oratory Reference Neutrality** convergence of 2020, or ***HORN*** for short. (HORN seems appropriate since the outer ear + ear canal form a horn-like flared tube which is responsible for much of the departure from simple flatness in the HORN frequency response curve.)

The Sennheiser HD 600 has become legendary for its natural-sounding playback since its release just before the 21st century began. If we compare the HD 600's measured frequency response with the curve in Fig. 5 we get:

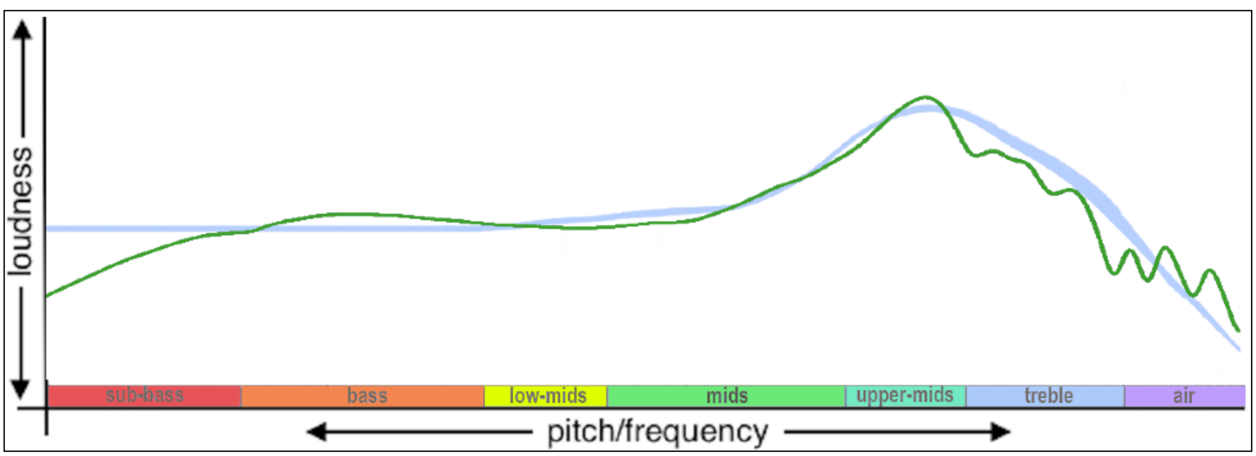


Fig. 8: Sennheiser HD 600 compared to HORN (source: Headphonesdatabase.com)

Flashback 1997: In its product manual Sennheiser simply refers to the HD 600 as being tuned to a **diffuse field response**. *Diffuse field* is the technical term for the sound measurement at the eardrum when the sound has equal loudness at all frequencies and at all directions. (See Appendix D for more info, if interested.)

A typical diffuse field curve looks similar to, but not identical to the loudspeaker curve in Fig. 2. Importantly, the ear gain rise in the high frequencies is every bit as high as in Fig. 2. We see from Fig. 5 that, given Sennheiser used a diffuse field response, they also modified it to correct for room gain as we did in Fig. 4. A true, unmodified, diffuse field response would mean that the green line in Fig. 7 would reach as high as the green line in Fig. 2.

The loudness drop on the far left of Fig. 8, followed by the slight overshoot in the bass, results from the engineering team having to cope with a large number of technical challenges. Few headphones come as close as the HD 600. Another factor is that frequency response is only one of several auditory goals the designers are trying to optimize. Spatial re-creation (sound stage and imaging), fine detail retention, dynamic range, dynamic impact and minimal distortion are also critical factors.

For another example, here is the (original) Focal Clear:

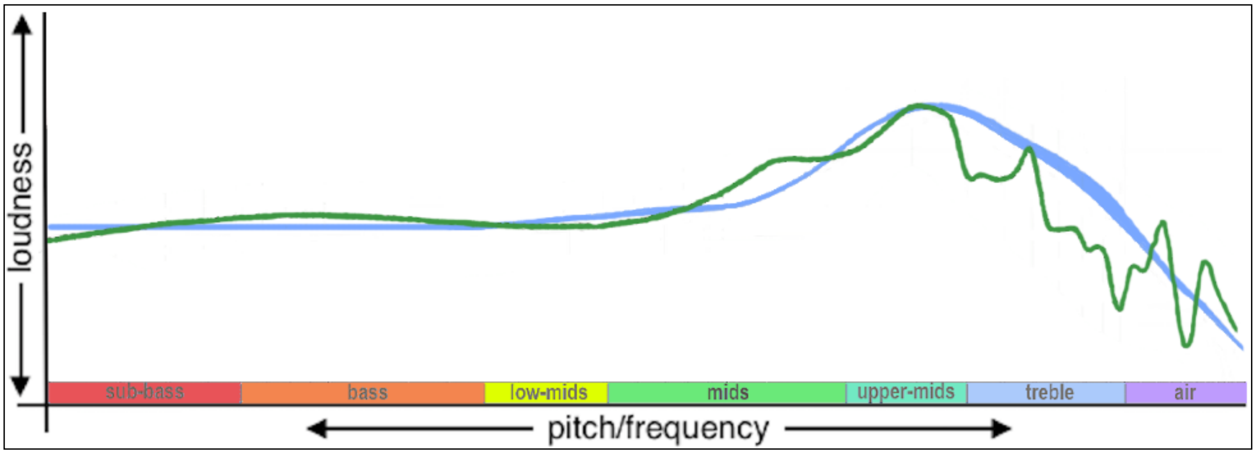


Fig. 9: Focal Clear compared to HORN (source: Headphonesdatabase.com)

The Clear departs a bit more from the neutral target curve, particularly in the treble range. We'll dig more deeply into this high frequency divergence in the Alternate approaches section below.

We could go on making such comparisons, but the result would be much the same. In my observation, the more a headphone is recognized by the headphone enthusiast community as being especially neutral or faithful sounding to recordings, the more it tends to resemble HORN. The criticisms people make, such as the HD 600 having a slight thickness in the upper bass or the Focal Clear having a bit of treble peakiness, show up as departures from HORN when we overlay their measurements with HORN. Headphones that people tend to report as less faithful to the source show greater departures from HORN. Crucially, none of them have anything like the Harman target's pronounced bass boost.

Thus, the converging evidence of the Oratory target, the Harman target excluding the bass boost and the rough community consensus regarding which headphones are neutral (but in addition see Appendix A) points to HORN as being the equivalent of daylight white light for headphones. HORN gives us a reference point for the frequency response of a neutrally tuned headphone — one that should come quite close to accurately reproducing the loudness aspect of (accurately) recorded sound.

It has become a truism in the headphone community that there is no known definition of headphone flat/neutral. There certainly is no IEC standard for this. But if anyone would like to invest in the exhaustive research needed to make that determination, my money is on the Oratory target as being within a gnat's knee of what would be found.

However, there are still a couple more factors to consider. (Are we having fun yet?)

Ear morphology

HORN is based on the IEC standard/average human ear. What we have to consider is the great variety of shapes and sizes people's ears actually come in. And this is true for the ear canal as well as the more obvious outer ear.

Fig. 10: typical differences in human ear shape (source: Wikipedia Commons)

HORN may be accurate for a person with a hypothetical average human outer ear and ear canal, listening at some reasonable loudness. But we see from Fig. 10 how widely divergent ear shapes are.

Fig. 11, below, shows how much three main regions of the ear contribute to the total ear gain. Unfortunately, the graph shows sound arriving at a 45º angle to the ear. For headphones that angle would be closer to 90º — and we don't know how that would change the relative weight of the various components. What's important is that the mix will differ to some degree for each person. Your own ear canal might contribute more than an average amount but the concha and pinna of your own outer ear might contribute less. The shape of the blue line total ear gain in Fig. 11 would differ accordingly. Your particular total ear gain from all angles is a component of what is called your *head-related transfer function* or HRTF. (Your head, neck and upper body also have an acoustic effect. But taken together they have less effect on the over-all shape of the curve.)

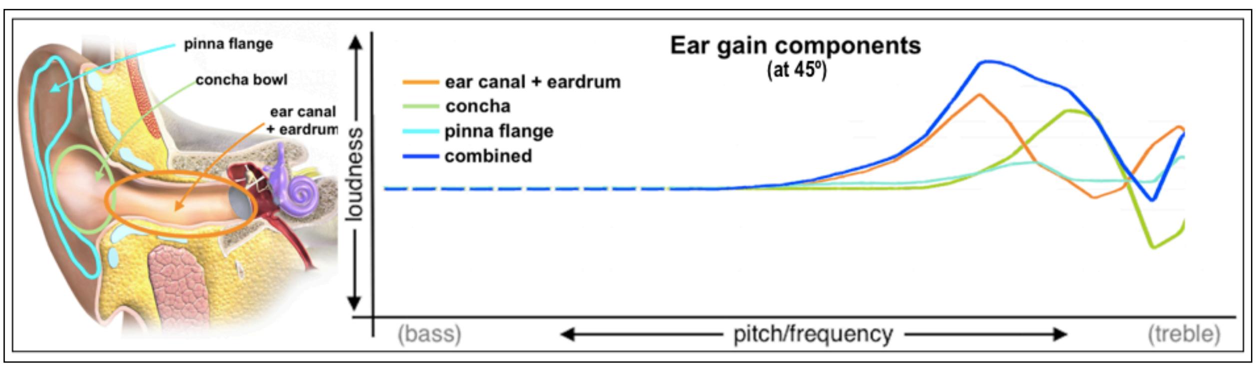


Fig. 11: contribution to ear gain from ear regions (source: Wikipedia & InnerFidelity)

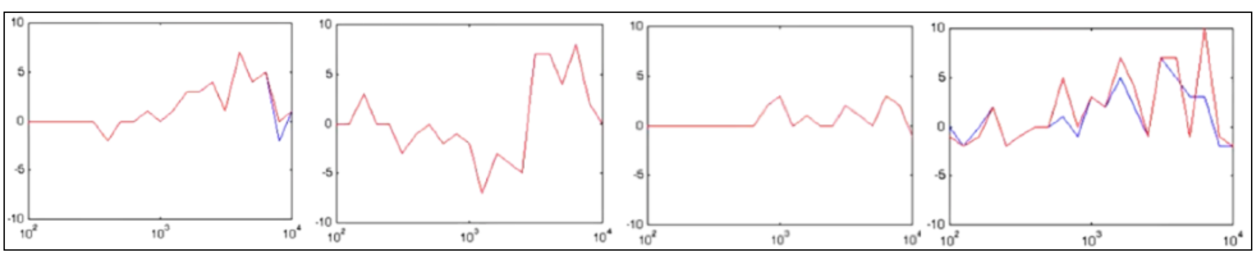


Fig. 12: insert microphone measurements of four different individuals wearing the same HD 600 headphone (source: David Griesinger, includes audio)

These individual differences also affect the high frequency cues our brains use to localize the source of a given sound. So the same headphone will produce a different soundstage and imaging experience for different people.

More critically, a reference curve like Oratory Optimum HiFi is defined in reference to a hypothetical average human ear. To quote Oratory1990: "The problem is that the standard deviation (how much a specific individual deviates from the average) gets higher at high frequencies. So much so that at frequencies above ~10 kHz it's virtually *useless* to specify an average." And even in the 6 to 10 kilohertz sibilance range it's already quite significant.

The frequent swings in loudness we see in the treble of any headphone graph, such as Figs. 8 and 9, are due to the interaction of that particular headphone with an IEC standard ear's own acoustics. The same headphone — any headphone — will have a different set of spikes and drop-outs when listened to with your ears. When your ear's own spikes coincides with one of the headphone's you've got trouble with treble indeed.

Psychoacoustics

But peel yet another layer off the onion and yet another question emerges: does any of this variation matter? Figs. 10, 11 and 12 above show the potential for a wide range of individual variation in frequency response perception across the entire ear amplification region from about 500 hertz to 10 kilohertz. Yet surprisingly, the Harman research we'll be looking at more closely below *indicates only a small variation* in personal preference across this entire ear gain region — the region that should be the most variable. In contrast, the Harman research shows a huge range of personal preference in the bass region, for which there seems to be no anatomical justification.

I noted above that your brain is designed to automatically cancel out the amplification resulting from the particular shape of your ears under normal circumstances. It is also designed to compensate for the often wildly varying acoustics of one room versus another and for any enclosed space versus the outdoors, at least in relation to speech perception. In fact, our brains do a myriad of processing of all auditory nerve input before we get to hear the result. This is all part of a field of study called *psychoacoustics*, the study of sound perception. This is a fairly young science that, as best as I can tell, is far from having investigated every nook and cranny of its domain. So far as I've been able to research, we are on our own in trying to tease out most aspects of the perceptual effects of psychoacoustic processing on headphone listening.

Anecdotally, there seem seems to be little consistency in what our brains are willing to do for us. Exactly the same unit of a particular model of beyerdynamic headphone will be described as being treble-emphasized but tolerable by three listeners to sibilance-intensive music, a bit problematic by two others, and intolerable by two more. That same headphone may have a significant recession in mid-range that will go completely unnoticed by some listeners yet will be a serious issue for others.

Given a chance, many find their brains will learn to compensate for the inaccuracies of a reasonably accurate headphone. Audio enthusiasts call this familiar phenomenon *brain burn-in*. Headphone enthusiasts are also quite clear that no amount of brain burn-in is going to make a piercing treble spike or a shouty mid-range play nice. And switching from one model headphone to a different model can at least temporarily defeat this ability pretty thoroughly.

None of this individual variation in subjective experience contradicts the validity of the HORN curve. So far as I can tell, we each have a different set of tolerances for frequency responses that *depart* from the HORN curve. You can play with EQ to determine where your preferences and sensitivities to departures from HORN lie. Armed with this knowledge plus an accurate headphone frequency response graph you can predict whether the tuning of a given headphone will work for you. Too much departure from your personal version of HORN may well result in a persistent frequency response annoyances, such as boominess, muddiness, sibilance or shrillness.

The search for the fun factor

So HORN might be a good target for headphone designers to shoot for if the goal were to please the perhaps five percent of potential customers who want anything resembling accuracy and who listen at moderate loudnesses. Presumably, the other 95 percent are looking for something more like this:

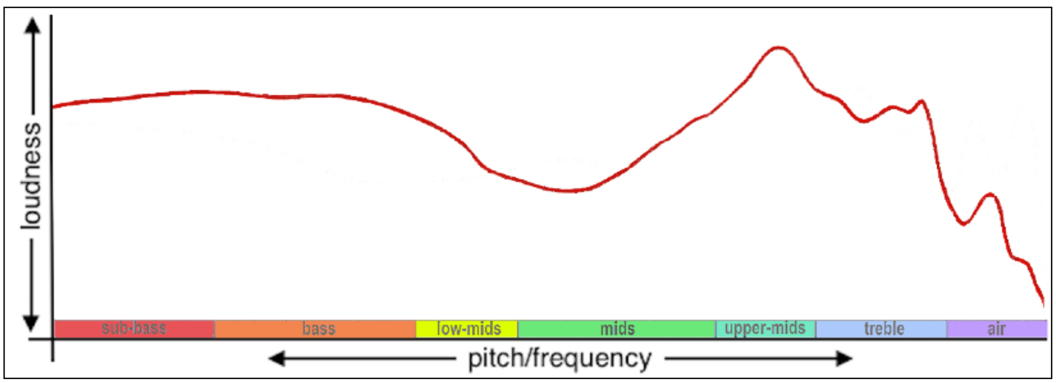


Fig. 13: example consumer preference curve. (source: rtings.com)

And many headphones actually measure more or less like Fig. 11. This is what consumer demand dictates. Immediate grab. Instant party time. The problem is that it fails miserably when listening to something like a jazz performance or a love ballad, where voice and instrument quality actually matters:

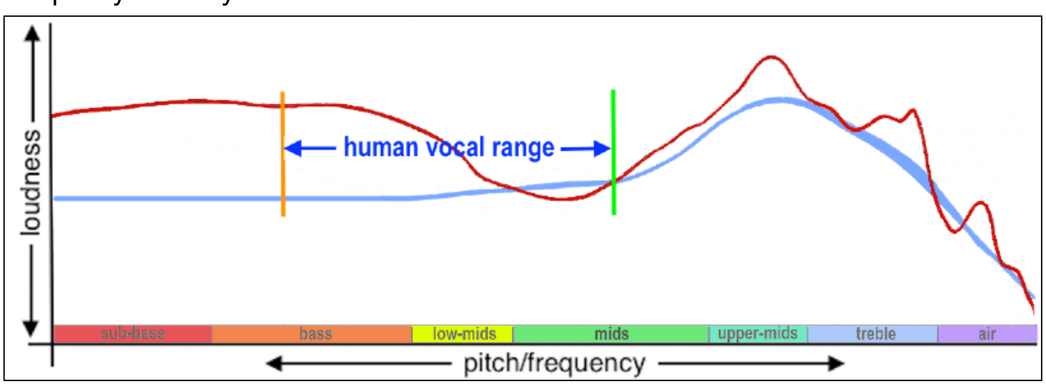


Fig. 14: standard male + female vocal range

Compare the portion of the red line in Fig. 14 between the orange and green lines with the same portion of the HORN blue line, which actually rises slightly rather than plummeting. It's generally still possible to recognize a singer's voice even when distorted as extremely as shown in Fig. 14. It's also possible to recognize yourself stretched and pinched in a fun house mirror.

Whether that's what you want to look like is another matter. (Of course, I exaggerate. Aficionados simply call this recessed mids and no big deal.)

Sean Olive, Todd Welty and colleagues at Harman International (not pictured above) set themselves the challenge of finding a single frequency response curve for headphones that would be most enjoyable to the greatest percentage of people … but importantly remain enjoyable while listening to a wide variety of music. As we saw above, their final result looks like this:

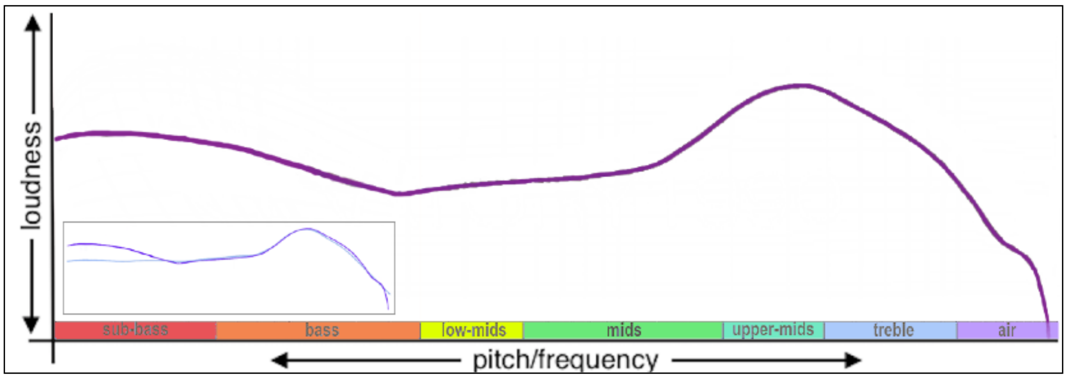


Fig. 6 (repeated): Harman target. Source: InnerFidelity.com.

As a nod to listener preference there is definitely a bass elevation. (Ask a typical restaurant goer how much salt to put on a dish. Then ask a haute cuisine chef.) But that bass gently tapers off where the bass range does — before the mid/vocal range. This curve was achieved by having about 250 people of different ages, sex, nationality and auditory training freely modify the bass and treble response of a headphone while listening to a variety of music samples.

However, as alluded to above, it's not that everyone came up with the same curve. Instead there was a range of variance:

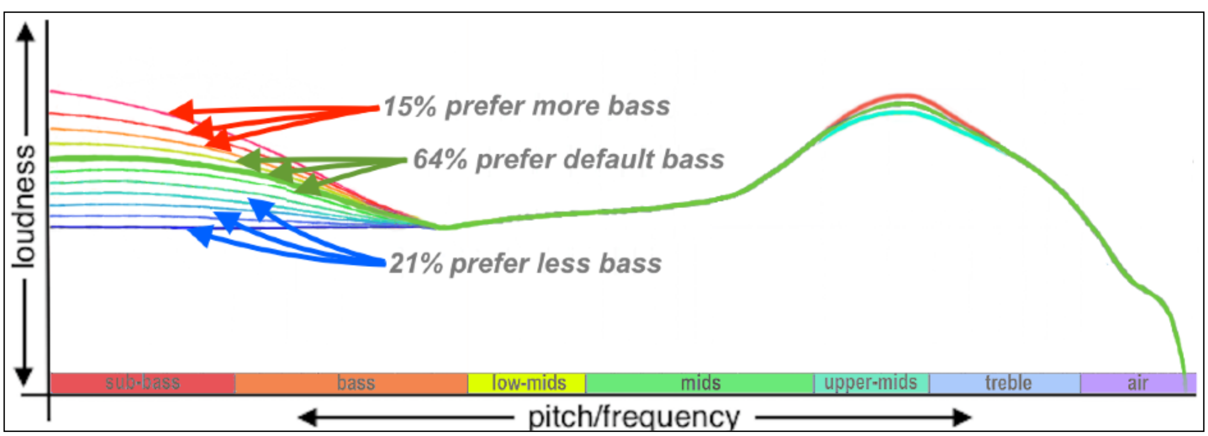


Fig. 15: Harman target plus some individual variations. Source Oratory1990, Sean Olive.

(And, yes, at least one individual actually preferred a slight bass reduction.) The purple line curve of Fig. 6 gets all the attention, but the research is more nuanced than just that, as we see in Fig. 15. Fig. 11 tells us there is no anatomical basis for this range of bass preference. Anatomically, it should be the right half of the graph, not the left, that shows all that variance. But if you're trying to manufacture headphones that sell, Fig. 15 is what you need to pay attention to.

It's easy to theorize that the bass variability of the Harman results indicates that people simply hear the measured bass sound pressure as representing perceptually different levels of loudness. If that were the case, however, a significant percent of the population would complain that a headphone with a ruler flat bass response like the Hifiman Arya has a rolled off bass instead of a flat bass. Similarly, a percentage of people would report that a headphone with elevated bass, like the AKG K361 or the Audio-Technica M50x, has a flat or even rolled-off bass. Instead, people seem to be pretty consistent in subjectively reporting whether a given headphone has elevated, flat or rolled-off sub-bass, mid-bass and upper-bass. This is anecdotal, but should be relatively easy to study.

Circling back again to the opening analogy, if the neutrality curve of HORN is a daylight white light bulb, the median Harman target curve in Fig. 6 is a warm white light bulb. In other words, a compromise between strict practicality and the dictates of the human auditory pleasure response.

Alternate approaches

Early on, first the free field, then the diffuse field ear measurement approaches were co-opted as tuning regimes for headphones. But both ignored the tempering effect of room gain. We've explored the linear speaker + room gain approach resulting in the HORN curve. Are there other possibilities?

Alternative 1: industry average

Above, we used the Sennheiser HD 600 and the Focal Clear as a quick check on the validity of HORN. However, over time Sennheiser moved on from the HD 600, first to the HD 650 in 2003, then to the HD 660S at the end of 2017:

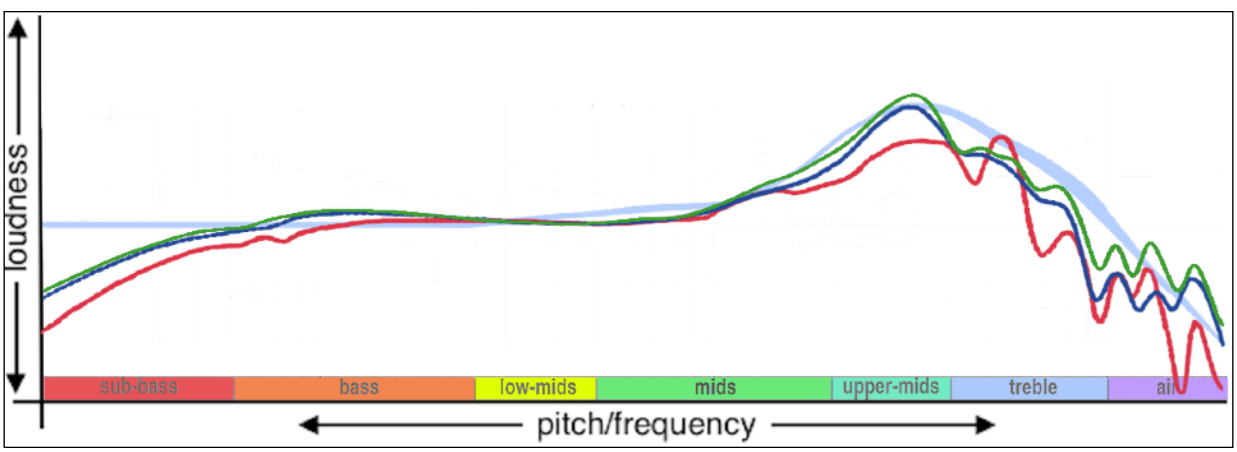


Fig. 16: Sennheiser HD 600, HD 650, HD 660S and HORN (source: HeadPhoneDatabase.com)

We see the green-blue-red progression toward an ever-lower, flatter ear gain hump. Similarly with Focal's two neutral-leaning models, plus their recent Clear Mg:

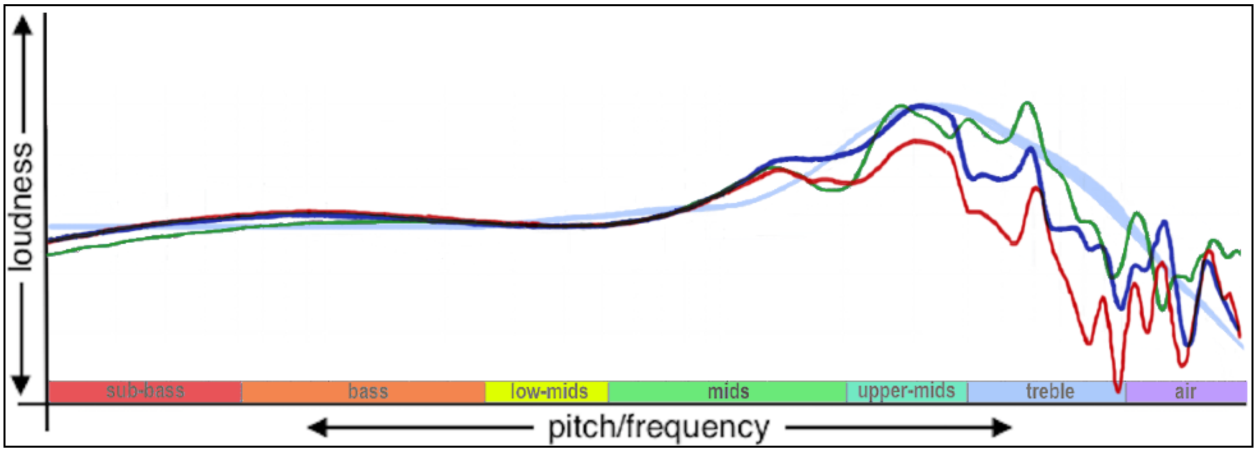


Fig. 17: Focal Utopia, Clear, Clear Mg and HORN (source: HeadPhoneDatabase.com)

Same idea. (Focal had to end production of their 2016 Elear due to lack of demand, yet now its frequency response has been reincarnated in the form of the Clear Mg. Less treble = more bass? Seems a dubious equation.)

Let's pursue this ear gain reduction creep a little further. For Fig. 18, below, I took the average of the frequency responses of fifty of the most "neutral" headphones I could find, but including those with a Harman-like bass elevation. The elevated bass headphones are shown in red and are mostly closed-back, the non-elevated bass ones are shown in green and are mostly open-back:

- Abyss Diana Phi
- AKG K361
- AKG K371
- AKG K612
- Audeze Mobius
- Audeze LCD-1
- Audeze LCD-XC
- Audio-Technica M40x
- Audio-Technica M50x
- Audio-Technica M70x
- Audio-Technica R70x
- Audio-Technica ADX5000
- Aurora Audio Borealis
- Beats Solo Pro
- beyerdynamic DT-770 Pro
- beyerdynamic DT-880 Pro
- beyerdynamic TYGR 300R
- beyerdynamic DT-1990A Pro
- Creative Aurvana Live!
- Dan Clark Aeon 2 Noire
- Drop+Focal Elex
- Drop+Fostex TH-X00 Ebony
- Drop+Sennheiser PC38X
- Focal Celestee
- Focal Radiance
- Focal Clear
- Focal Utopia
- Hifiman HE400i (2020 rev)
- Hifiman Sundara (2020 rev)
- Hifiman Ananda
- Hifiman Arya
- Koss Porta Pro
- Koss ESP950
- NAD Viso HP50
- Ollo SR4
- Oppo PM-3
- Philips SHP9500
- Philips Fidelio X2
- RAAL Sr1a
- Sennheiser HD 560S
- Sennheiser HD 600
- Sennheiser HD 650/6XX
- Sennheiser HE1 v1
- Shure SRH 840
- Sony Z1R
- Stax SR-009
- Superlux HD-668B
- Superlux HD-681B
- Warwick Sonoma Model 1
- ZMF Auteur (lambskin)

Individual frequency response graphs for all the listed headphones are assembled here.

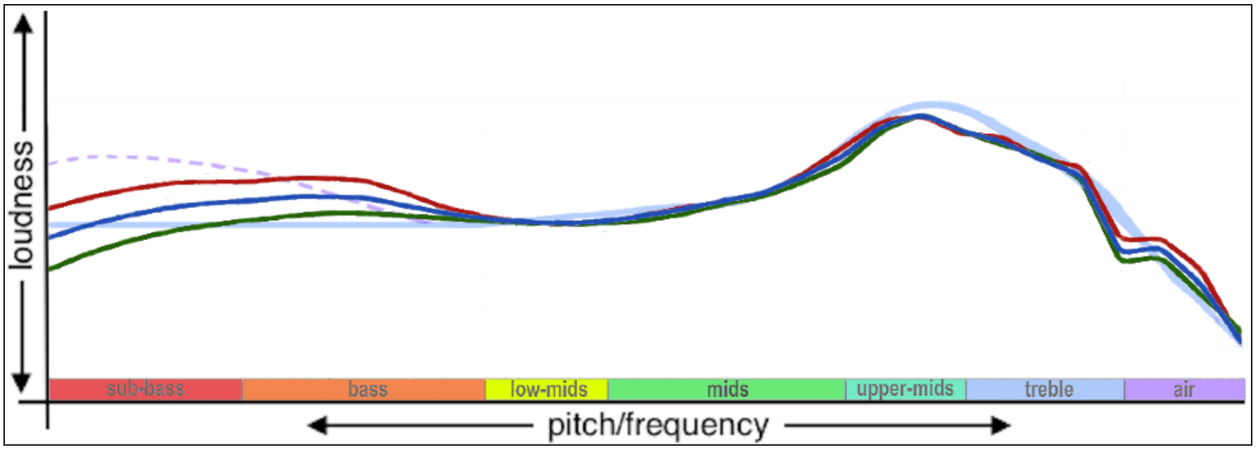


Fig. 18: average of 26 Harman-like, avg. of all 50, average of 24 neutral-leaning + HORN and Harman

Forgive me for slipping into full geek mode for a minute: Looking at the Fig. 18 total average (dark blue), with an average ear gain peak at 9 decibels, we can see that manufacturers are increasingly putting their money on a noticeable undershoot of the Harman target curve's ear gain rise. While there is a rise between the 250 hertz start of the mid-range and 1 kilohertz, it starts late at 500 hertz. Interestingly, in terms of left/right position, the ear gain peaks at about 3.2 kilohertz versus the 3.4 to 3.5 kilohertz maximum of the Oratory and Harman targets. Then, further to the right, there is a cliff-like drop-off from 8 to 10 kilohertz — which supports the theory that a drop in this area is an important localization cue.

Yet, the Harman research shows a wide cross-section of people in various demographics preferred the relatively higher ear gain peak of the 2018 Harman (and therefore also the Oratory) target. I suspect the undershoot of the Harman target ear gain we see in Fig. 18 is at least in part due to the difficulty in matching the Harman target's ear gain area precisely enough. By undershooting it, I suspect, designers are preferring to steer clear of the inevitable complaints that this treble spike or that treble spike sounds piercing. Equally, I suspect the undershoot of the Harman bass boost is due to the simple difficulty in designing that much bass into even an closed-back headphone while maintaining an accurate mid-range. And one thing that's remarkable about Fig. 18 is the near exact match between the average of all three curves in the mid-range through the treble, except for the highest (air) octave.

Regardless of what Oratory Optimum HiFi or the Harman target indicate regarding what's actually neutral, the curves in Fig. 18 may be the more practical targets, given today's manufacturing technology, for purely passive (non-DSP) headphones.

Alternative 2: community and influencer contributions

The 2-channel and home theatre community is filled to the brim with individuals creating their own signature room gain curve. The headphone enthusiast community is divided between diffuse field traditionalists (they actually mean diffuse field + room gain), Harman target proponents (either the original 2013 version or the final 2018 version) and the pox-on-all-your-houses, I-like-what-I-like majority. But there are also a number of influencers promoting their own neutrality candidates, whether based on theory or on sheer subjective preference. I'm sceptical that any of these I've seen so far will pass an eventual IEC standards litmus test. But I've been wrong before…

Wrap-up

We've looked at neutral from multiple sides now. We now have a measurement+theory neutrality candidate in HORN. We have a listener preference candidate in the Harman 2018 target. We have an average of multiple neutral-sounding headphone measurements. So what is a neutral/accurate frequency response for a headphone? Depending on your purpose it could be different things:

- For a theoretical neutral reference based on the IEC603318-4 standard ear, to my knowledge the HORN target is as close as we have at this point and likely within a gnat's knickers of some ultimate curve.
- For a manufacturer designing a new model, on the bass end it's more about how much bass you can achieve for open-back and closed-back while still honouring the HORN mid-range. For the high frequencies it's about how close you can come to matching the HORN ear gain profile with minimal peakiness and minimal overshoot.
- For personal use where maximum accuracy is essential, you need to have your own head-related transfer function measured using insert microphones. (No easy task.)
- For personal use in which you simply want to hear things as closely matched to the intention of the recording but not knowing your HRTF, use EQ starting with Oratory Optimum HiFi or the linear bass Harman target, then adjust bass level and ear gain peak level to remove any sense of excess or deficiency.
- For listening pleasure with a focus on hearing the recording as intended but without a lot of technical fuss, you'll simply have to gamble on which of the 50 headphones listed above you want to take a chance on. None match any target curve precisely. Although the Sennheiser HD 560S comes quite close to matching the HORN target and the AKG K371 comes very close to matching the Harman target, neither excel at fine detail reproduction.

You can use the graphing tool on headphonedatabase.com to compare various headphone models to both the standard Harman and the Oratory Optimum HiFi targets.

✣ ✧ ✣ ✧ ✣ ✧ ✣

And that concludes this episode in the Headphone Essentials series. In the next episode we put both the Harman and the Oratory Optimum HiFi targets to work at the exciting task of *Interpreting headphone frequency response graphs* (http://daystarvisions.com/Music/index.html).

Appendix A: flashback 2013 — a bit of headphone history

Going back to the opening logic for a neutral headphone frequency response, Fig. 2 and Fig. 4 were based on a linear speaker measurement. That measurement was done primarily by Todd Welti working with Sean Olive as part of the early research leading to the 2018 Harman over-ear target. The original, 2013, version of the Olive & Welti Harman target was evidently created the same way as was Fig. 4, but using a different room gain.

The room gain curve they used starts with a hefty bass boost that their prior research showed to be more closely aligned with consumer preference. Beyond the bass they employed a well-known alternate room gain of a one decibel loudness drop per octave. This jibes better with the acoustics of a small venue (or home listening environment), where in contrast the B&K room gain averages both large and small venues. The result:

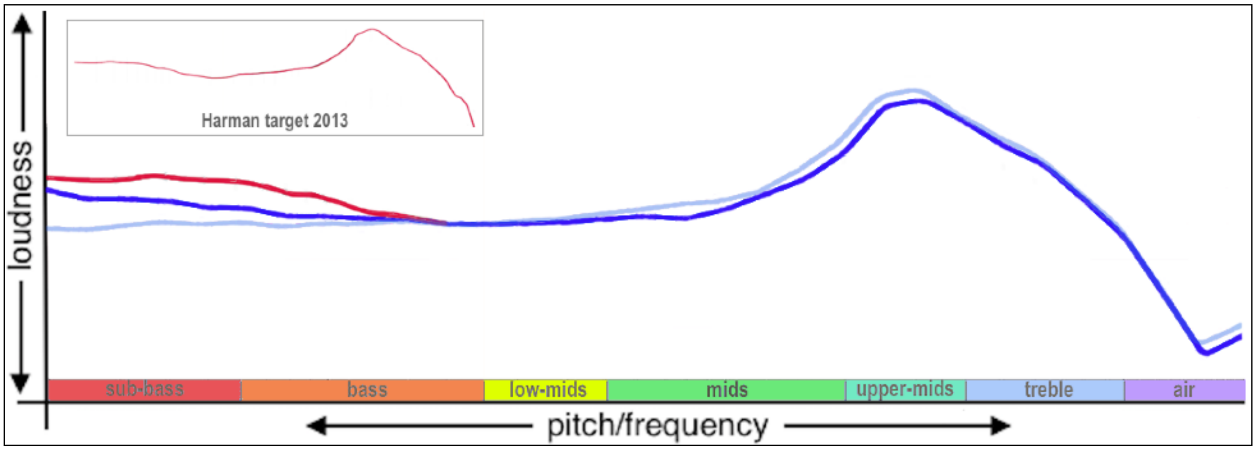


Fig. A1: the 2013 Harman target bass boost (red) combined with a 1 decibel/octave room gain applied to the linear speaker curve (blue) and compared to the Fig. 4 curve (pale blue)

Tyll Herstens of now defunct InnerFidelity.com introduced this to the headphone community at the time and followed the Harman team's work thereafter with further reports.

Appendix B: solving the compensation crisis

If you've got this far, you've either become or already were pretty familiar with making sense of frequency response graphs as presented in this document. But there exists a more intuitive presentation and one that is extensively used on the internet due to it's greater accessibility to a more general audience.

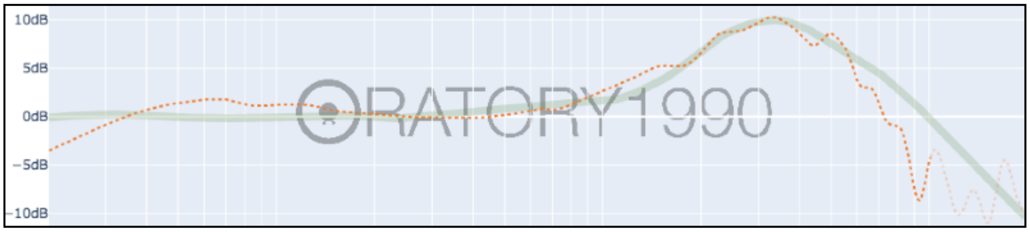


Fig. B1: headphonesdatabase.com raw data graph for Sennheiser PC38X

Fig. B1 shows the raw data for Sennheiser's latest gaming headphone in familiar form.

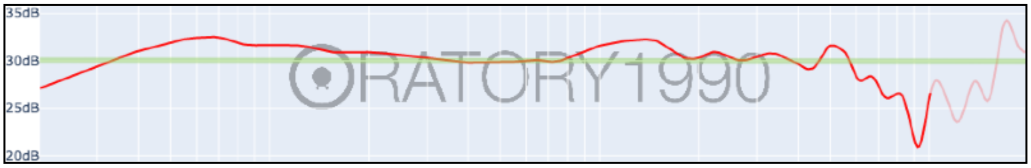


Fig. B2: headphonesdatabase.com compensated data graph for Sennheiser PC38X

But the same web site offers an alternate presentation shown in Fig. B2. If we add a horizontal line to emphasize the faint 20 decibel line, Fig. B2 essentially becomes an error bar showing the divergence between the headphone measurements and the green target curve shown in Fig. B1. That target curve happens to be the Oratory Optimum HiFi we've become familiar with above.

But the user can equally select the Harman target as the compensation basis:

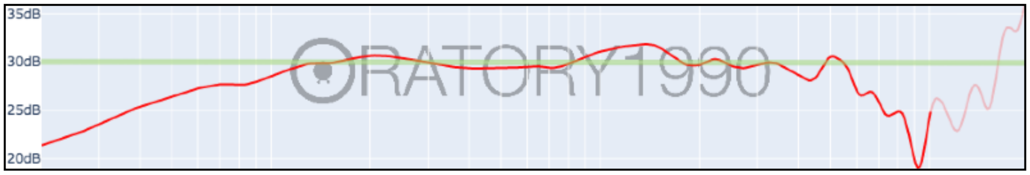


Fig. B3: headphonesdatabase.com compensated data graph for Sennheiser PC38X

… or even a diffuse field curve:

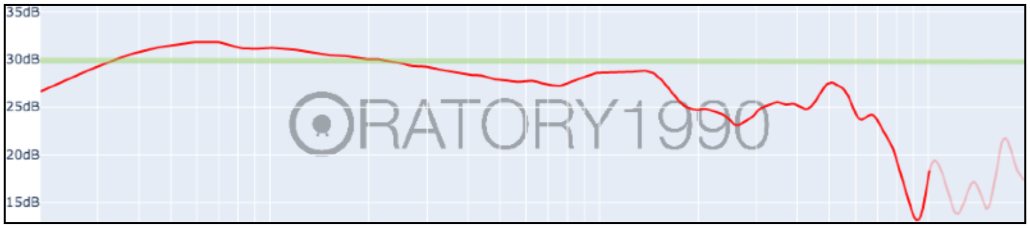


Fig. B4: headphonesdatabase.com compensated data graph for Sennheiser PC38X

All three show exactly the same headphone and exactly the same measurement data. And this is exactly what you'll find in great abundance on the web: compensated measurement graphs based on wildly different target curves *but* — unlike on the Oratory site — presented with no labeling to specify which target was used. Unlabeled, Fig. B3 says to the uninitiated viewer that the PC38x is a bass-light headphone. Fig. B4 says it's a bass-heavy headphone.

If the graph viewer is shopping for a bass-emphasized headphone, a Harman-compensated graph might easily mislead the shopper into thinking the headphone he's viewing is significantly weaker in the bass than it actually is. While a diffuse field compensation will tend to do the opposite. A neutral target curve desperately needs to become the go-to standard for compensated frequency response graphs. And waiting for some far-off future IEC approval is simply not an acceptable option.

Appendix C: technical versions of key graphs

Below are the key graphs from the text above but presented with standard log scales.

The ⅓-octave decibel numbers I used for plotting certain non-headphone measurement graphs may be found on my website. The Brüel & Kjær curve is based on visual inspection of the published graphs and has no greater authority than that:

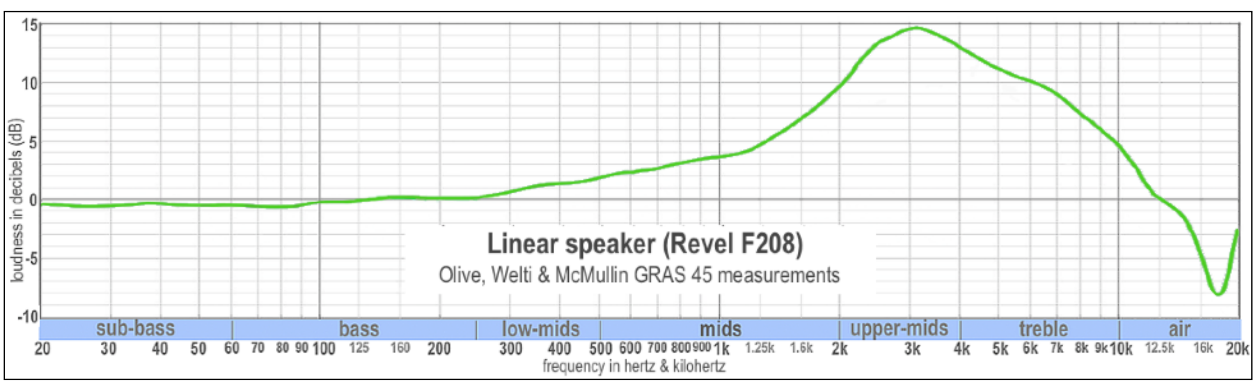


Fig. 2a: flat speakers measured at the eardrum (source: Jaakko Pasanen/AutoEQ)

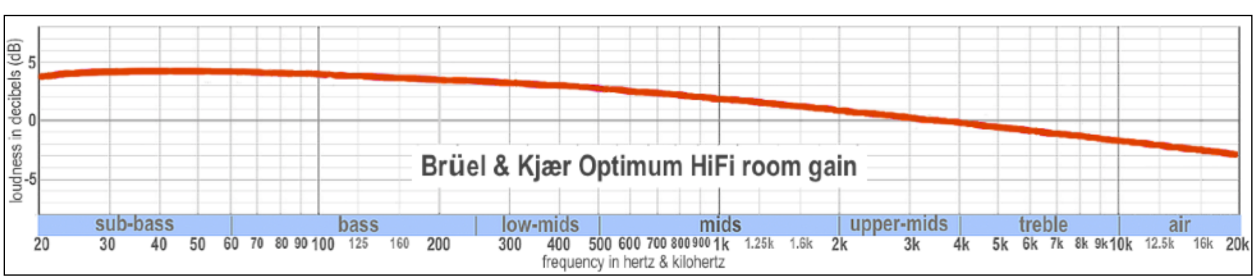


Fig. 3a: room gain frequency response (source: Brüel & Kjær)

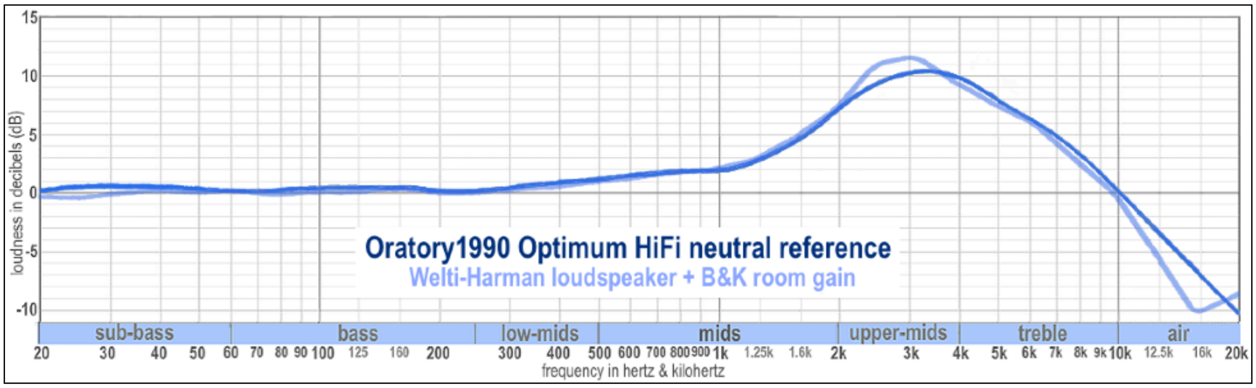


Fig. 4a+Fig.5a: Welti-Harman+B&K room gain and Oratory Optimum HiFi

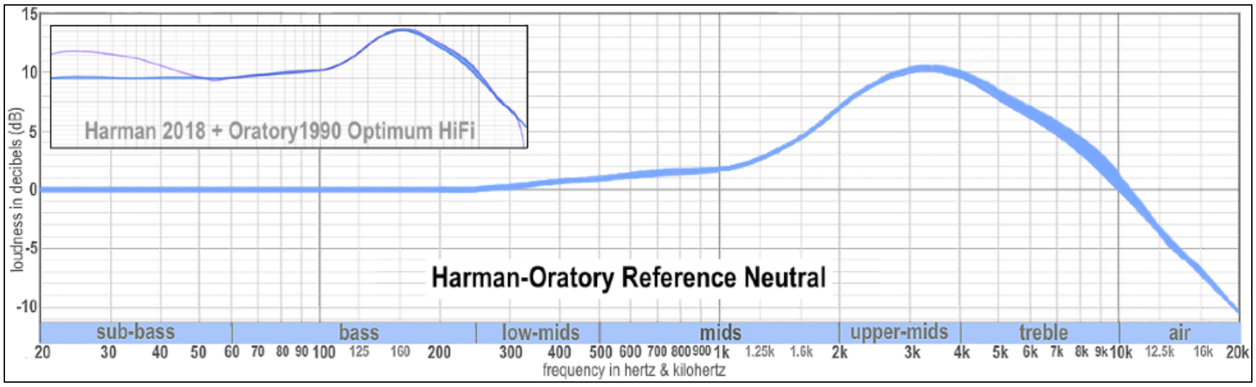


Fig. 7a: HORN

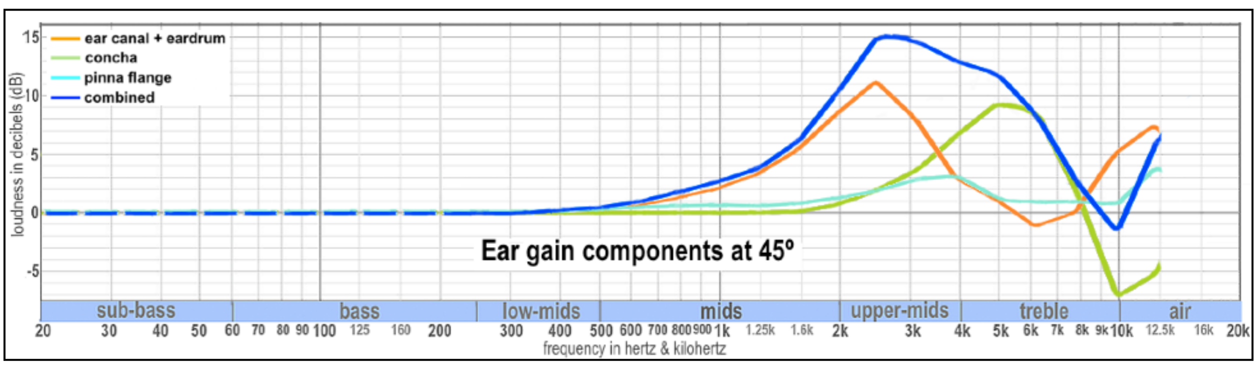


Fig. 9a: contribution to ear gain from ear regions (source: InnerFidelity)

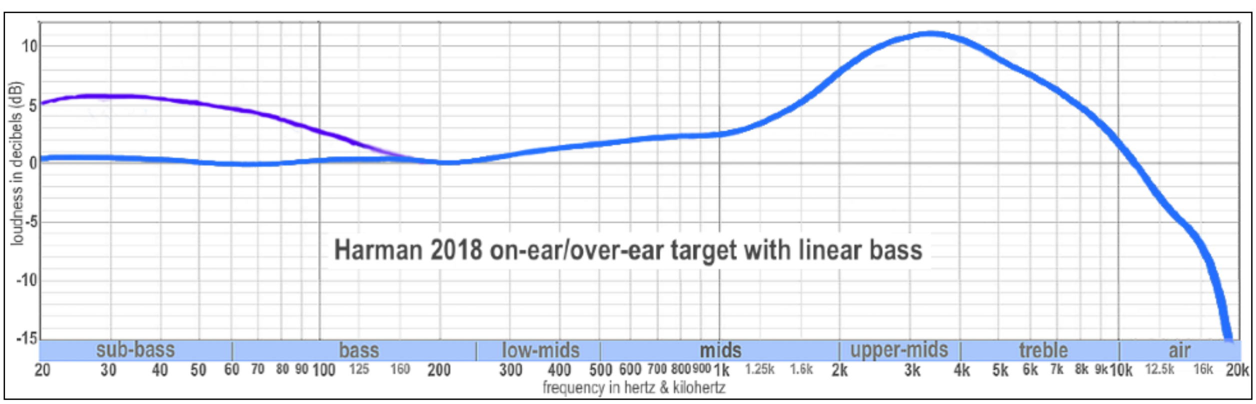


Fig. 14a: Harman target + Harman linear (source: Jaakko Pasanen/AutoEQ)

The following graphs are based on measurements made by Oratory1990, Resolve or Crinacle on (IEC603318-4) GRAS 43/45 rigs with anthropomorphic pinnae (accurate out to 10 kilohertz):

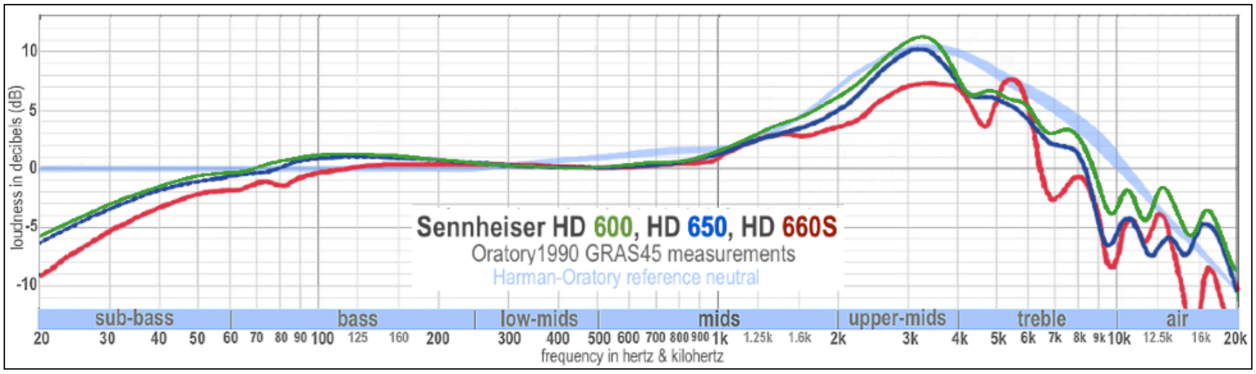


Fig. 16a: Sennheiser HD 600, HD 650, HD 660S and HORN

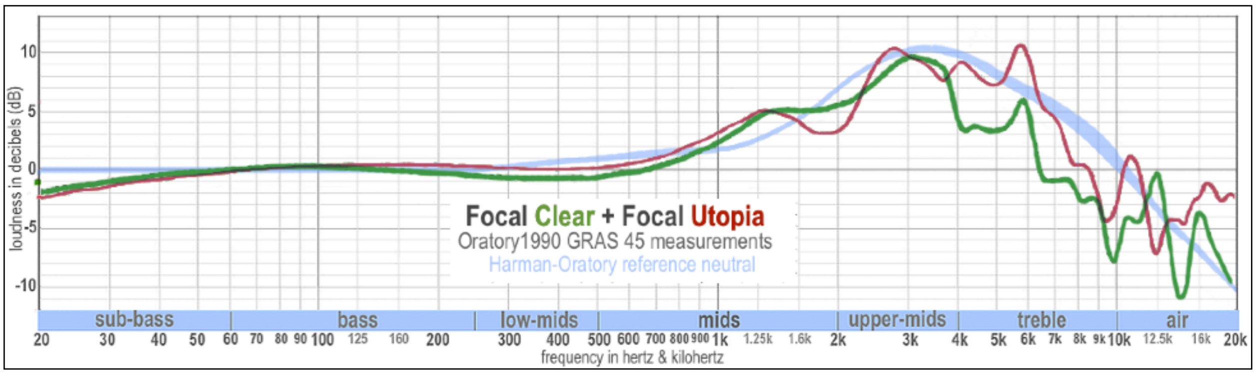


Fig. 17a: Focal Clear, Utopia and HORN

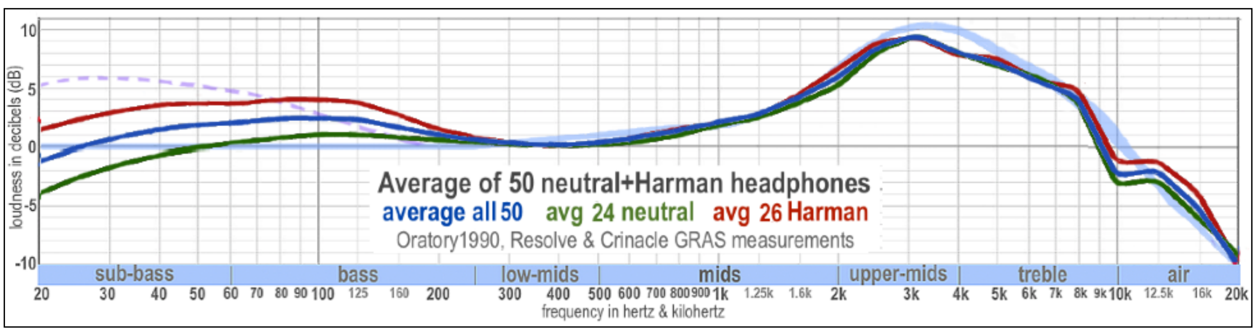


Fig. 18a: average of 26 Harman-like, avg. of all 50, average of 24 neutral-leaning + HORN and Harman

And lastly, here's a bonus spaghetti graph showing all 50 headphone plots that are averaged together in Figs. 16 and 17:

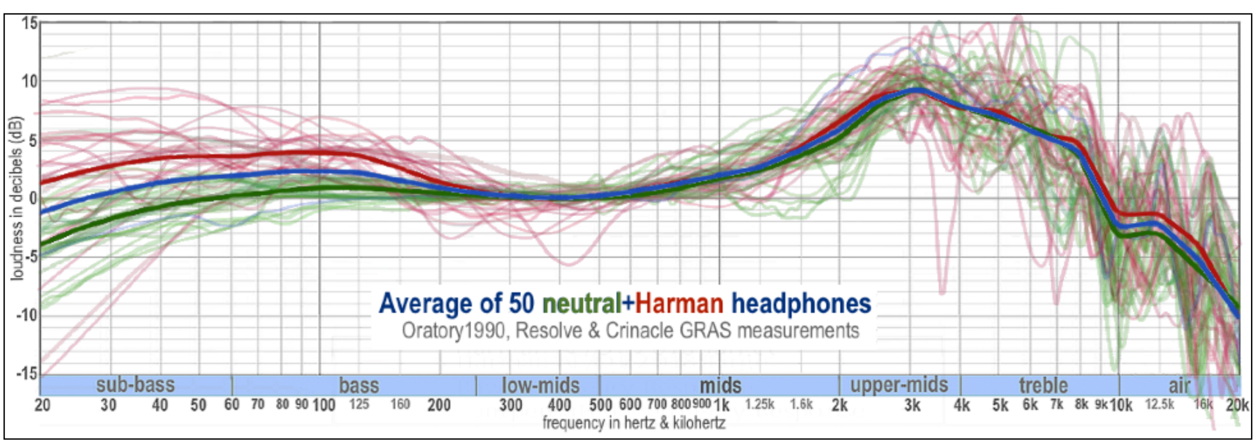


Fig. C1: average of all 50 plus actual measurements of neutral + Harman headphones

Not that I expect anyone to untangle the individual strands, but the Harman-like headphones curves are pale red and the neutral-leaning headphones are pale green. This gives an idea of the degree of departure from the average lines both above and below. View the individual graphs here.

Appendix D: diffuse field headphone tuning

As noted above, the concept of a diffuse field tuned headphone is still very much alive among enthusiasts. This goes back to at least the late 1990's when Sennheiser proclaimed it's HD 580 and HD 600 headphones as being diffuse field (instead of free field) exemplars. They even used the diffuse field descriptor for the HD 800, which is quite a stretch. In other words, in the headphone domain diffuse field had come to mean simply non-elevated bass plus some semblance of ear gain. Here are the results of a couple of diffuse field studies:

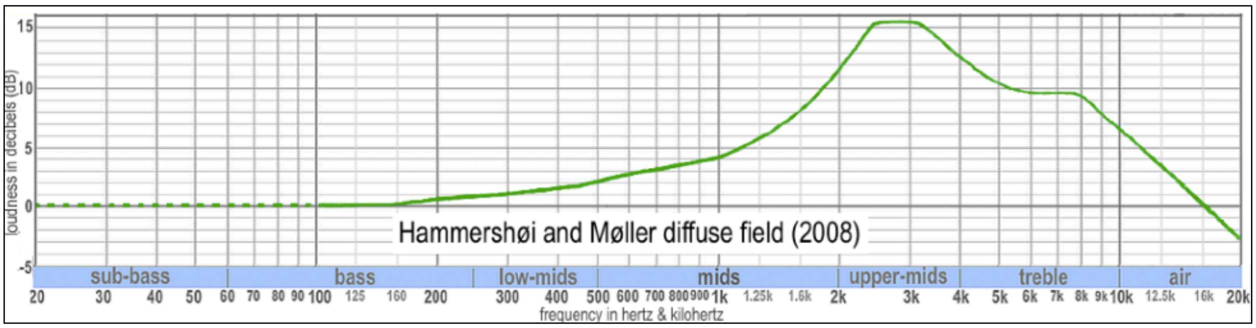


Fig. D1: Hammershøi and Møller DF (Source: see 12th entry in Appendix E below)

While the Hammershøi and Møller diffuse field is the most familiar at this time, there has been more recent research, including this one provided by acoustic engineer Oratory1990 but not attributed:

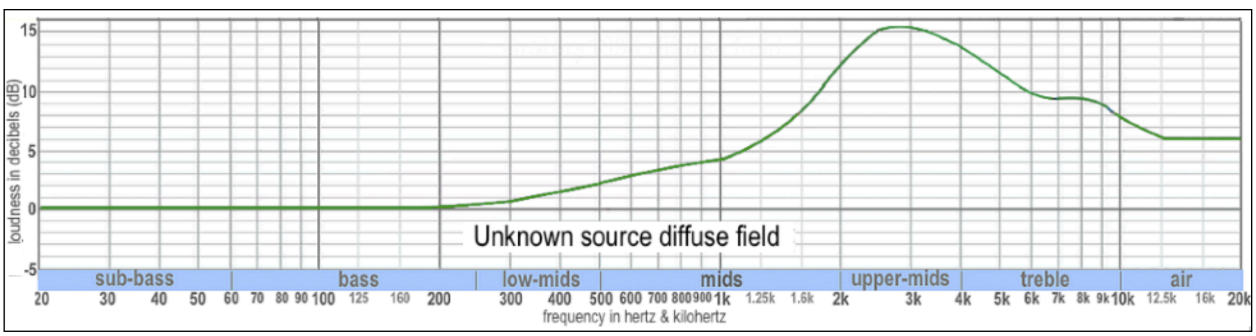


Fig. D2: unknown recent diffuse field (source: HeadPhoneDatabase.com)

The pronounced difference between the two at high frequencies shows once again just how problematic this portion of human hearing is. Here's how they compare to each other and to the linear loudspeaker curve we used to derive a precursor to HORN:

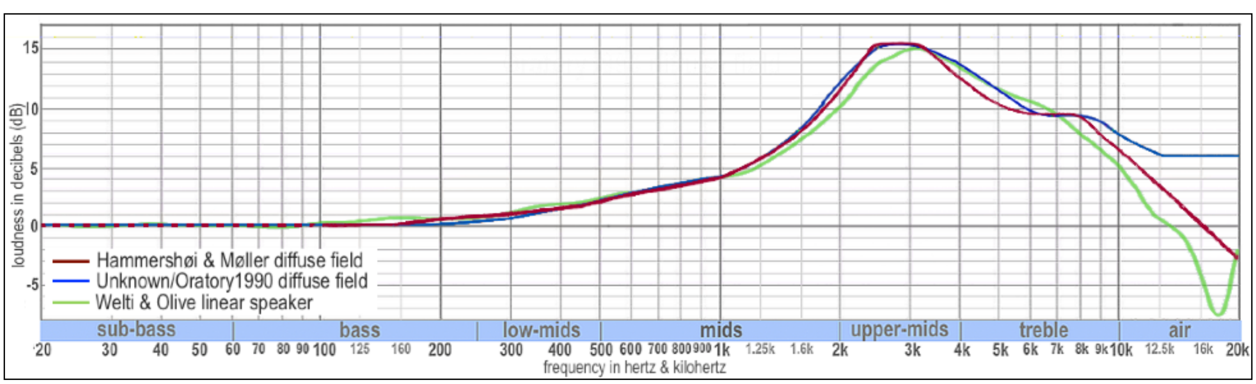


Fig. D3: diffuse field graphs compared to linear speaker graph (Figs. 2 and 2a)

Merging these ear response measurements with the B&K room gain curve, we get:

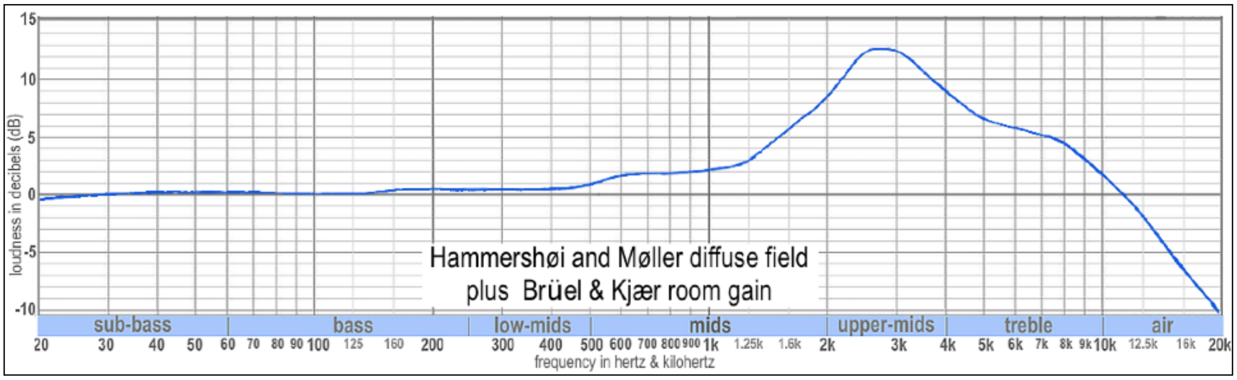


Fig. D3: Hammershøi and Møller DF + B&K room gain

…and…

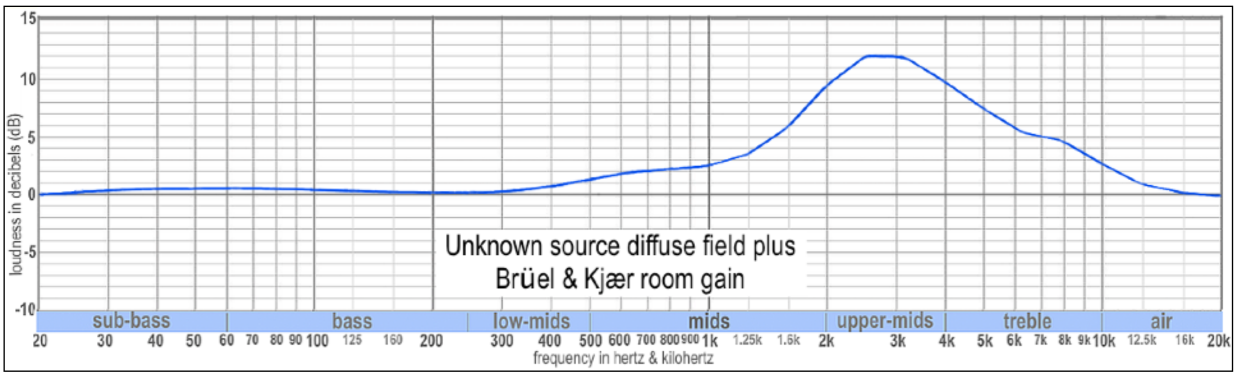


Fig. D4: DF from unknown source + B&K room gain

Both of these have an ear gain peak between 12 and 13 decibels. That much ear gain more or less jibes with the HD 600, but certainly not with the HD 650 or HD 800/800S. We could instead use a different room gain curve, like the common one decibel per octave:

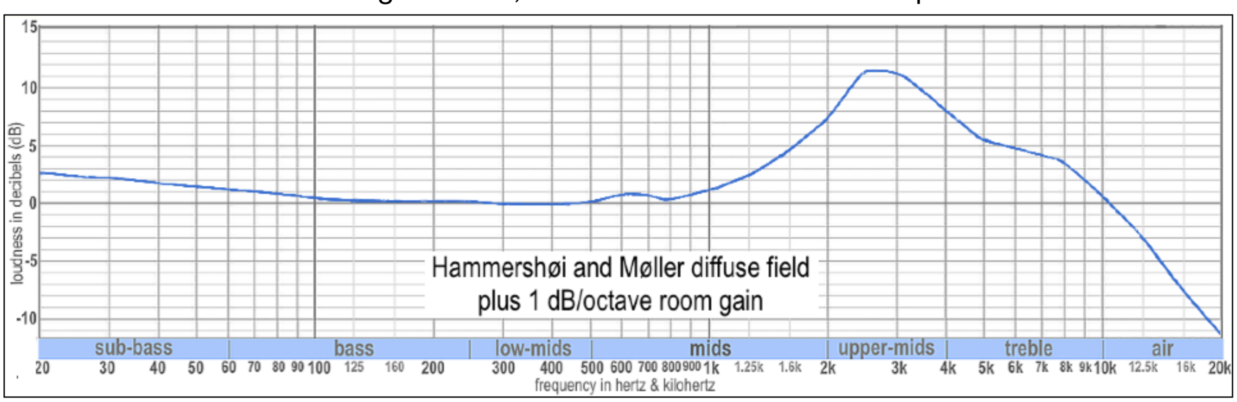


Fig. D5: H&M DF + B&K room gain

This brings the ear gain peak down to 11½ decibels but introduces a bit of bass plus sub-bass elevation. I'm sure many would welcome this, but it hardly resembles a typical diffuse field tuned headphone and is mainly appropriate for small venue recordings. We also see the curve in Fig. D5 as part of the initial Harman research presented in Appendix A.

In any case, it's not entirely clear that either the free field — on-axis directivity ear response measurements — or diffuse field — omni-directional ear response measurements are the appropriate snapshot of the human ear response to blend with room gain in order to provide a target for an accurate headphone frequency response. So all the more impressive that Axel Grell's team at Sennheiser was able to get as close to HORN as they did with the HD 600 in the 1990s.

Appendix E: further reading/viewing

Some source material:

1. **Brüel & Kjær**, "Relevant loudspeaker tests in studios in Hi-Fi dealers' demo rooms in the home etc." (1974), https://www.bksv.com/media/doc/17-197.pdf
2. **Tyll Herstens**, "Headphone Measurements Explained - Frequency Response Part One", https://www.stereophile.com/content/innerfidelity-headphone-measurements-explained
3. **Warren TenBrook**, "Warren TenBrook's Summary of Head Measurements at Harman", https://web.archive.org/web/20190711222725/https://www.innerfidelity.com/content/warren-tenbrooks-summary-head-measurements-harman
4. **Warren TenBrook**, "An Acoustic Basis for the Harman Listener Target Curve", https://web.archive.org/web/20160924084851/http://www.innerfidelity.com/content/acoustic-basis-harman-listener-target-curve
5. **Chris Plack**, "The Musical Ear", https://nmbx.newmusicusa.org/The-Musical-Ear/
6. **David Griesinger**, "Binaural hearing, Ear canals, and Headphones" (2016), https://www.youtube.com/watch?v=a-JGAobDwGs
7. **Oratory1990**, "Differences between the Harman Curve and Diffuse Field", https://www.reddit.com/r/headphones/comments/78x77b/initial_impressions_of_2016_audeze_lcd2f_with/doyj84e/
8. **Oratory1990**, list of EQ presets [and measurements], https://www.reddit.com/r/oratory1990/wiki/index/list_of_presets and https://headphonedatabase.com/oratory
9. **Sean Olive**, Do Listeners Agree on What Makes a Headphone Sound Good?, https://www.youtube.com/watch?v=f1EVZVDaeLw
10. **Olive and Welti**, AES 139 Presentation 2015 Olive and Welti Preferred Bass and Treble Levels, https://www.youtube.com/watch?time_continue=2&v=ySQV5OR71e4&feature=emb_logo
11. **Wikipedia**, "Head-related transfer function", https://en.wikipedia.org/wiki/Head-related_transfer_function
12. **D. Hammershøi and H. Møller**, "Determination of Noise Emission from Sound Sources Close to the Ears", *Acta Acustica*, Vol.94 No.1, January 2008