Headphone Essentials 5:

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

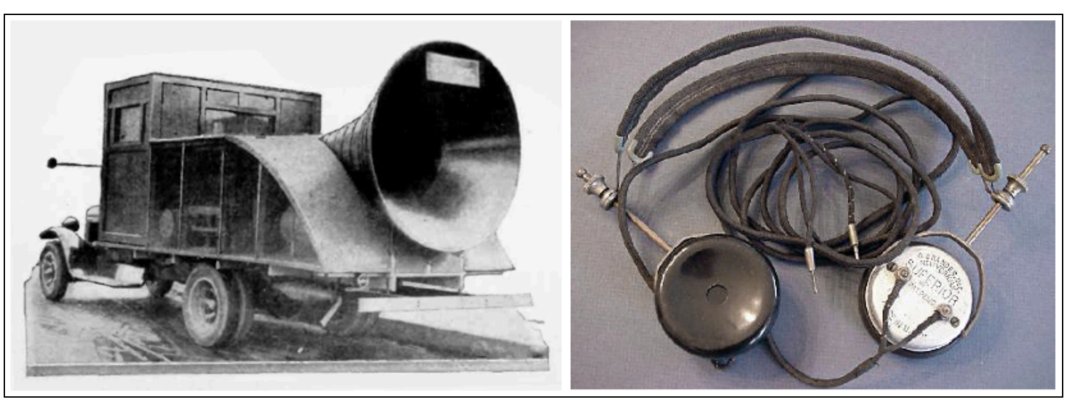
Note: this document is part of a instructional series. If you would like to start with more foundational information on the nature of sound and related material, see *Basics of Musical Sound*, *Basics of Headphone Sound* and *The Skinny on Headphone Frequency Response Graphs* at Headphone Essentials.

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 are purely my own. I provide references to easily available source material so you can form your own opinions. That this document is in its third 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:

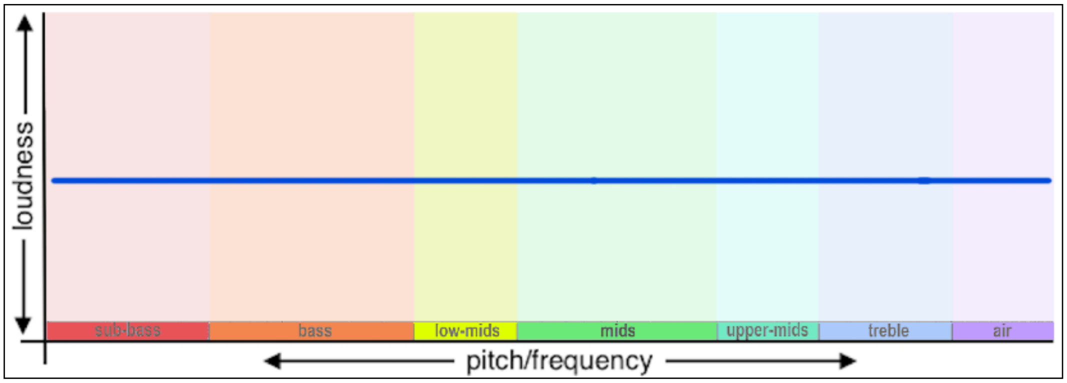


Fig. 1: flat frequency response

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:

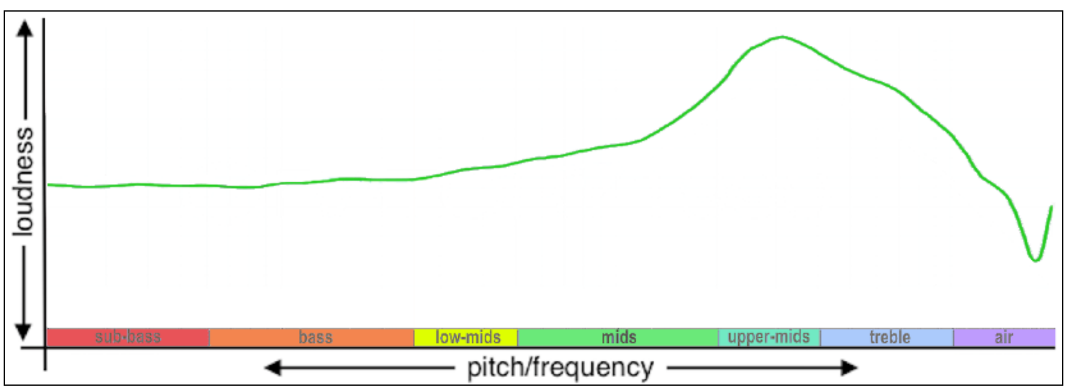


Fig. 2: flat speakers measured at the eardrum (source: InnerFidelity article, Fig.5)

The huge rise in loudness in 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 but reduces 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.

There is, however, a complication. When loudspeakers are used in a room, their sound output reverberates 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 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:

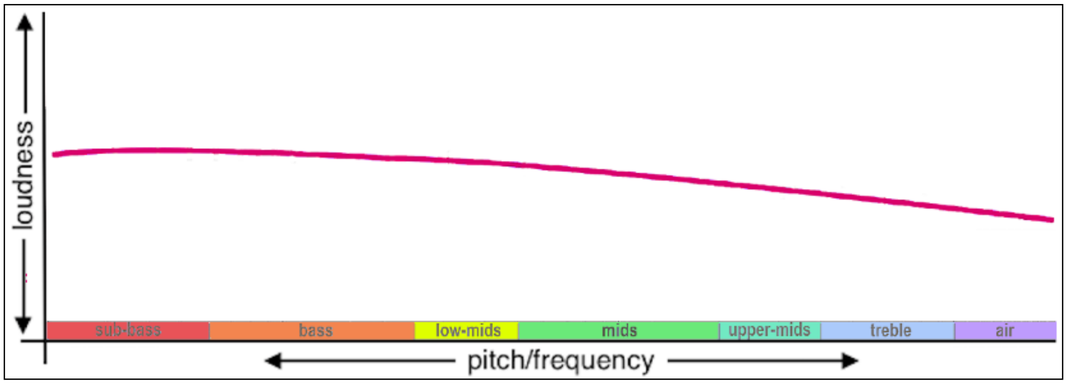


Fig. 3: room gain frequency response (B&K Optimum HiFi)

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:

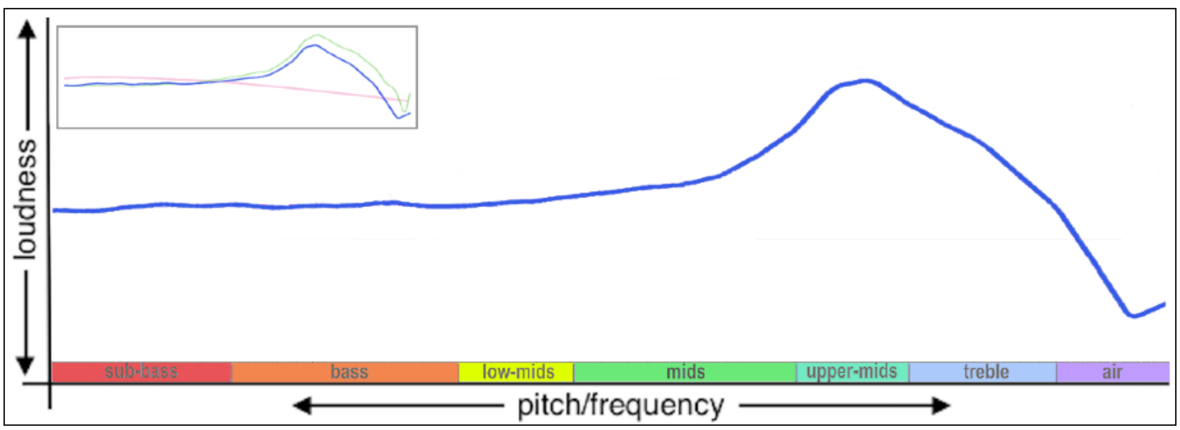


Fig. 4: Combined Harman loudspeaker measurement + B&K room gain

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 15½ 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 this for the simple reason that headphones don't work like loudspeakers in a room. We don't press our ears up against stereo loudspeaker cabinets as we do with headphones. Instead, speakers in a room create sound pressure waves that fill the air in the room *before* entering the ear from a complex variety of directions. In contrast, headphones shove sound straight at the ear canal. This is called *direct coupling*. It eliminates all or most of the selective high frequency amplification of the human ear and also has essentially zero room gain of its own. So for a headphone to reproduce a recording the headphone needs to artificially engineer in the high frequency boost shown in Fig. 4.

Fig. 4 is based on the only publicly available 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 a presumably more refined loudspeaker/eardrum measurement to produce a very similar, but presumably more accurate, curve:

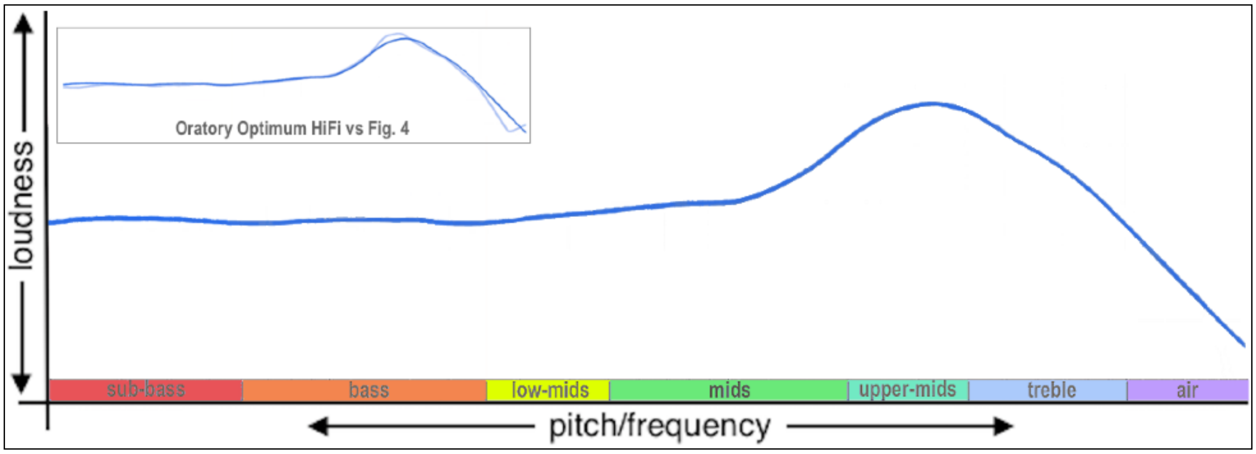


Fig. 5: Oratory1990 Optimum Hifi headphone reference curve (source: headphonesdatabase.com)

Headphone enthusiasts love to sneer at the Harman target curve (often mis-spelled as Harmon) that we see in Fig. 6:

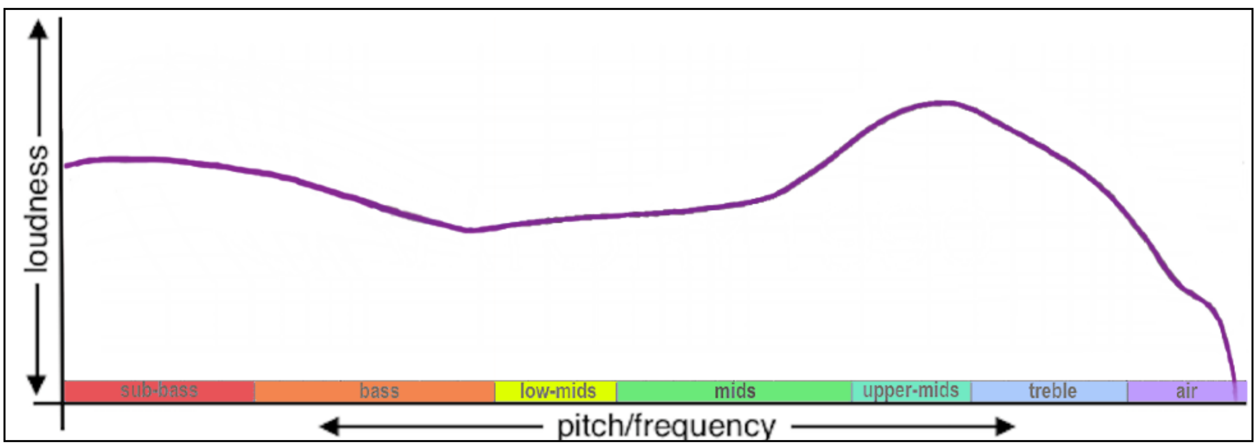


Fig. 6: Harman 2018 over-ear/on-ear headphone target curve

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.

This loudness curve was arrived at by having some 250 listeners of 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:

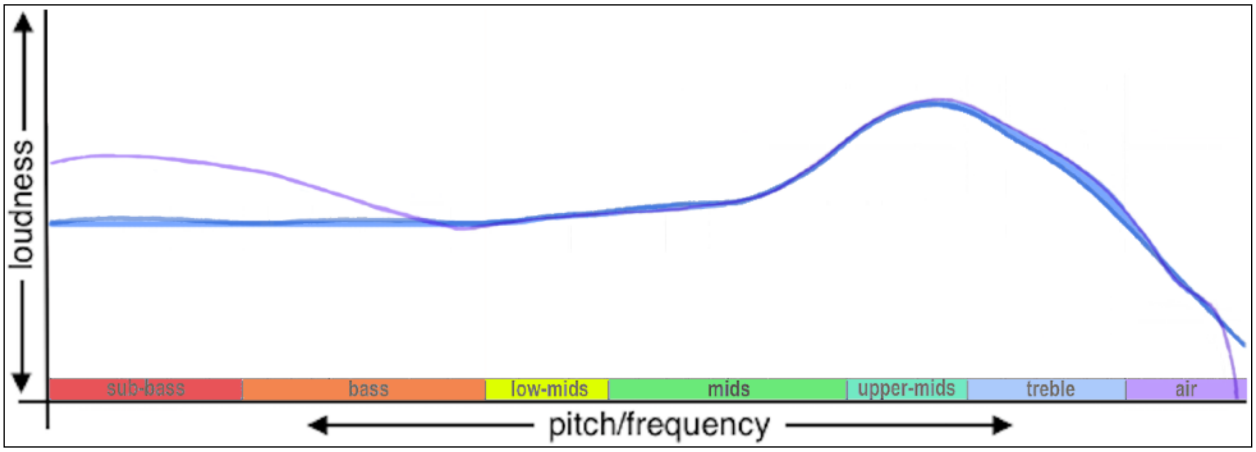


Fig. 7: Harman 2018 target compared to Oratory Optimum HiFi (source: Jaakko Pasanen/AutoEQ)

The match to the right of the big bulge in the bass area is uncanny. But what about that major divergence on the left? We'll look into this in more detail below, but 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.

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 plus ear canal form a horn-like structure 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:

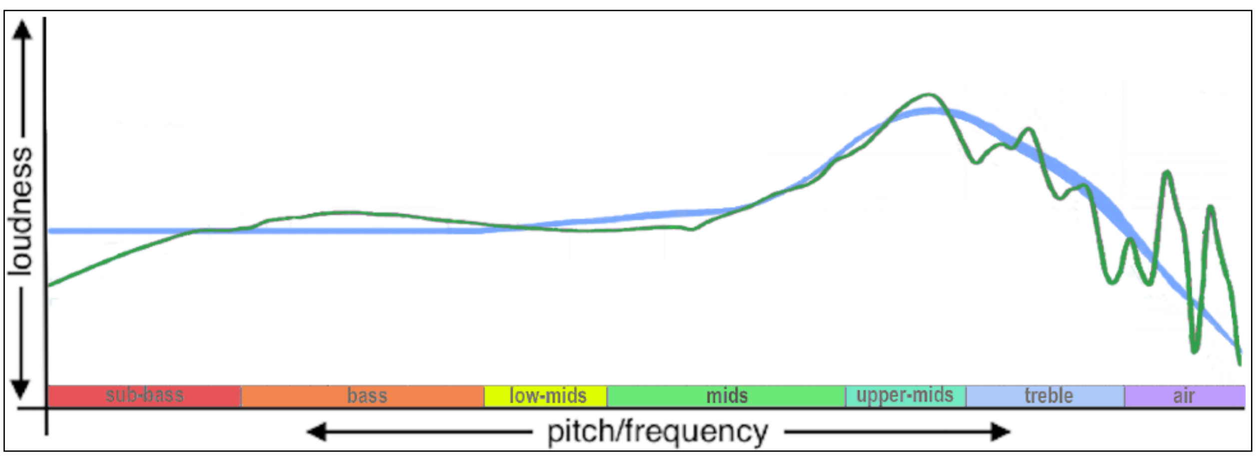


Fig. 8: Sennheiser HD 600 compared to HORN (source: Headphonesdatabase.com)

The loudness drop on the far left of Fig. 8, followed by the slight overshoot in the bass, is presumably the result of the engineering team having to cope with the same challenge that cone loudspeaker engineers nearly always face. In a stereo speaker pair each box typically houses two or three speaker cones of different sizes to cover the entire frequency range. In an open-back headphone typically a single speaker cone is used in each ear cup. But the challenges of keeping enough loudness in the lowest bass frequencies, while at the same time sculpting the ear gain rise in the higher frequencies, are reportedly huge. 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.

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.

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 blue line in Fig. 2.

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

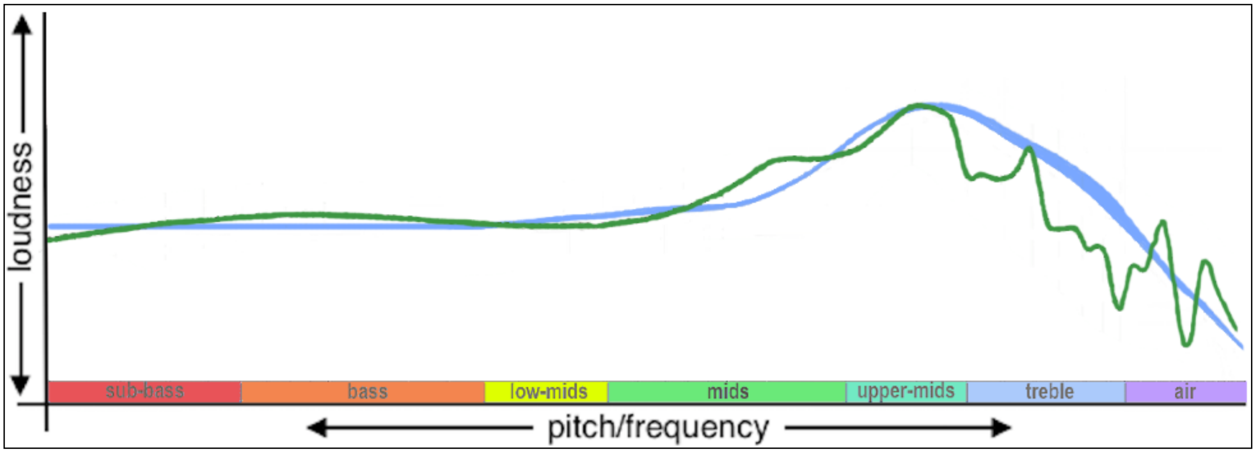


Fig. 9: Focal Clear compared to HORN (source: Headphonesdatabase.com)

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, 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 past the bass 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 and psychoacoustics

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. Again, for in-room loudspeaker listening this isn't an issue. Each person's brain knows how to compensate for his/her own ear anatomy.

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

But for headphone listening it very definitely is an issue. 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 is the main 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.)

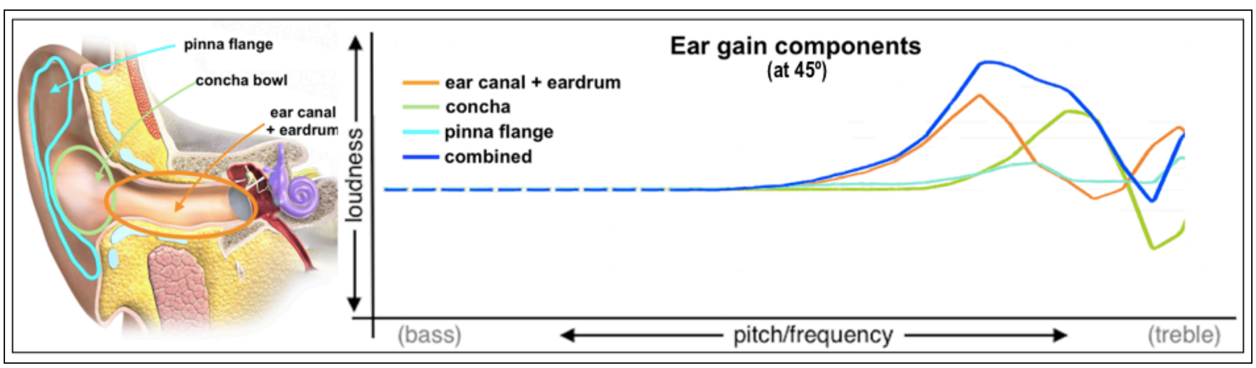


Fig. 11: contribution to ear gain from ear regions (source: Wikipedia & InnerFidelity)

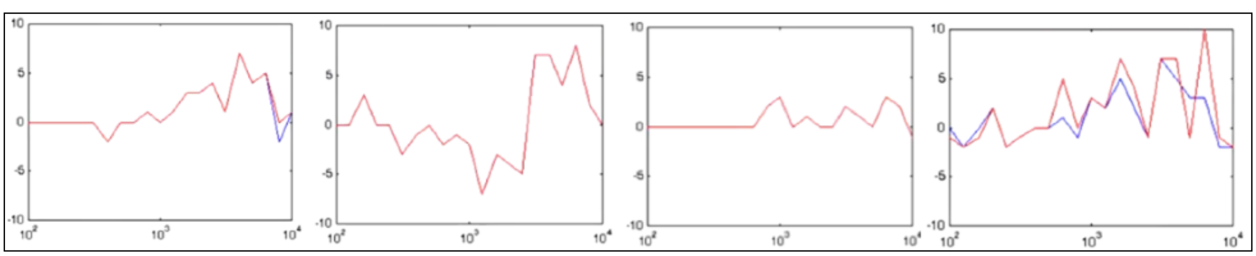


Fig. 12: insert microphone measurements of four different individuals wearing the same HD 600 headphone (source: David Griesinger, includes audio)

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.

The trouble with treble: As discussed, 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.”

The wild 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 the 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 real trouble indeed.

But peel yet another layer off the onion and yet another question emerges: does any of this variation matter? I noted above that your brain is designed to automatically compensate for 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. All this very much applies to live music and in-room loudspeaker listening.

But for headphones, with their direct coupling, all bets are off. Given a chance, your brain *may* compensate for a *certain amount* of departure of a given headphone from the frequency response that would be accurate for your ear shape and listening loudness. Not a lot seems to be known about this, but the idea is that your brain may create a model of how your headphone departs from accurate at each frequency that falls in the frequency regions it has evolved to manipulate. It would then use that model to correct for those inaccuracies. This is part of a field of study called psychoacoustics. And surprisingly, the Harman research we’ll be looking at below indicates only a small variation in personal preference across the entire ear gain region that Figs. 9 and 10 tell us should be the most variable.

Anecdotally, however, there seem to be serious limits, particularly at frequencies outside the vocal range, on how much inaccuracy your brain can correct for. And switching from one model headphone to a different model can at least temporarily defeat this ability pretty thoroughly. But 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.

Yet, even given all the above, HORN can be used as a reference point when shopping for a headphone when the goal is accurate recorded music listening. Your brain will likely overcome *some* departure from HORN in some areas. Too much departure from your personal version of HORN may well result in a persistent frequency response annoyance, 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 accuracy and who listen at moderate loudnesses. Presumably, the other 95 percent are looking for something more like this:

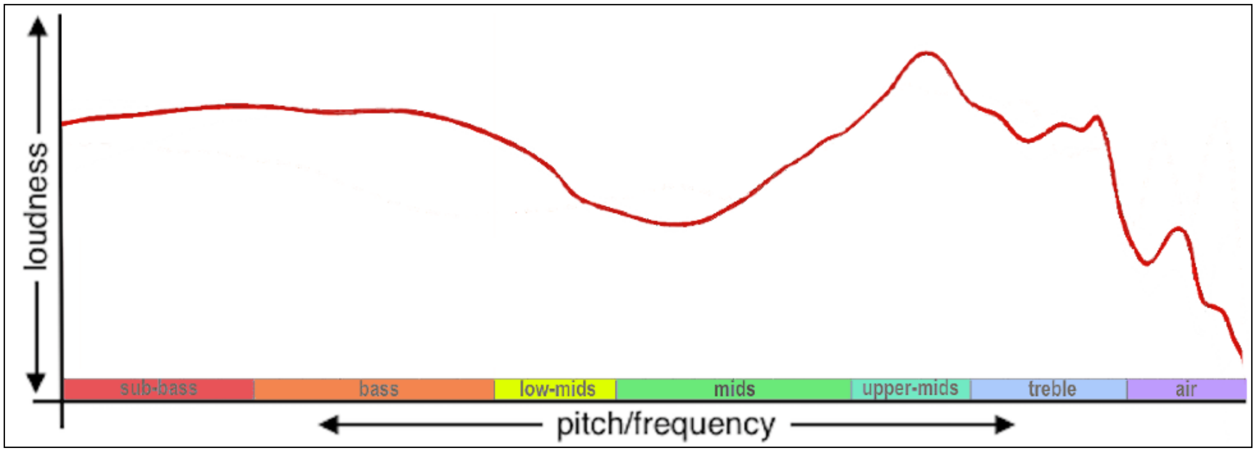


Fig. 13: example consumer preference curve. (source: rtings.com)

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:

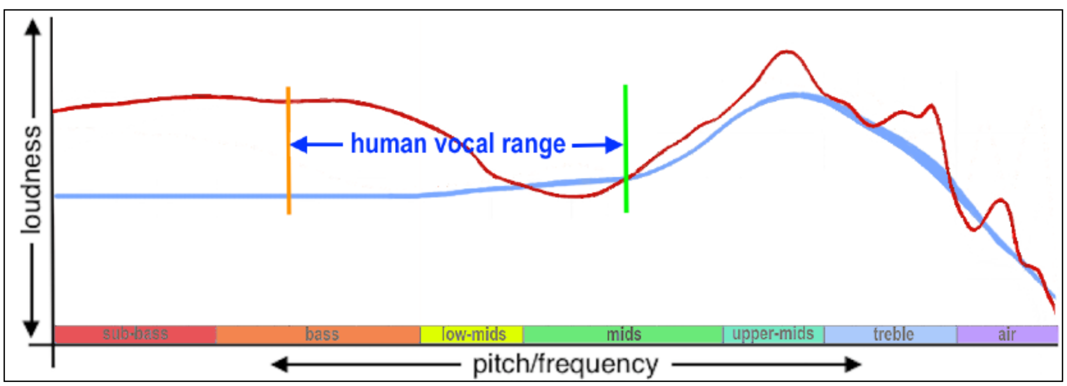


Fig. 14: standard male + female vocal range

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.

The whole flat/neutral/Harman thing

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:

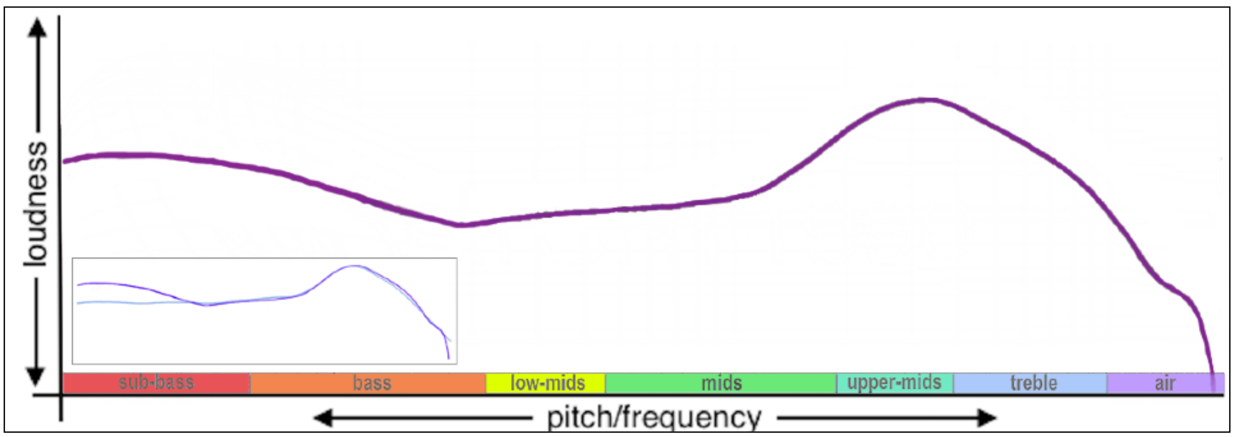


Fig. 6 (repeated): Harman target. Source: InnerFidelity.com.

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. Also, the ear amplification peak is slightly lower than in HORN to accommodate loud listening levels. 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 something like this:

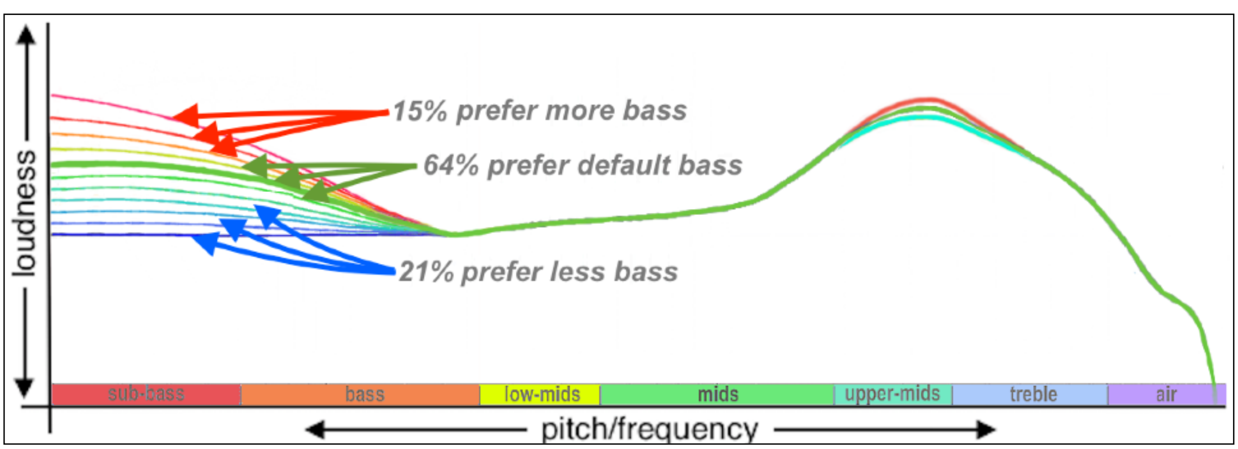


Fig. 15: Harman target plus some individual variations. Source Oratory1990, Sean Olive.

(And, yes, at least one individual actually preferred a slight bass reduction.) The purple line curve 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. 6 is what you need to pay attention to.

Circling back once 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.

However, it's not that the default six decibel rise of the standard Harman target is without consequences. The **presence of that much bass** effects the total tonal *balance* of a headphone's (or loudspeaker's) sound signature. This is easily heard when listening to a dense orchestral passage in which bass, mid-range and high-pitched instruments are all sounding at the same time. No live professional orchestral performance is going to have the sound that comes from the Harman target's balance. It also skews the bass/mids/treble balance a solo pianist is working so carefully to achieve. But for the smaller ensembles typical of popular music the effect is more easily ignored. Nevertheless, Sean Olive himself laments that every headphone would ideally come with a bass adjustment knob.

Some take-aways so far

In the world of 2-channel loudspeakers, an accurate loudspeaker is easily described by its flat-line frequency response once room effects are removed. But those very room effects are the great challenge for 2-channel. (This points to a vocabulary conundrum. Objectively measured, the only time flat = accurate is when an ideal loudspeaker is mic'd outdoors. Yet, subjectively, loudspeakers can sound flat indoors. And headphones that re-create that sound will as well.)

In contrast, in the world of over-ear and on-ear headphones, external room effect variations are virtually eliminated. The challenge is in re-creating a natural eardrum response. The combination of this re-created loudspeaker plus room gain is at least a good approximation of the frequency response of a hypothetically perfect loudspeaker system in an hypothetically ideal room. That said, there can be no one truly correct/accurate headphone tuning, if only due to personal ear shape variance. Even so, brain adaptation can and often does at least partially compensate for some departure from the ideal.

In any case, accuracy does not drive headphone sales. A headphone with market appeal typically has a highly boosted bass response that extends well into the mid-range frequencies, distorting vocal and instrumental sounds. The Harman frequency response curve is a carefully researched compromise between strict accuracy and consumer preference. But by its very nature in its default form it is a compromise that will satisfy about two-thirds of potential consumers.

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 just a few years ago:

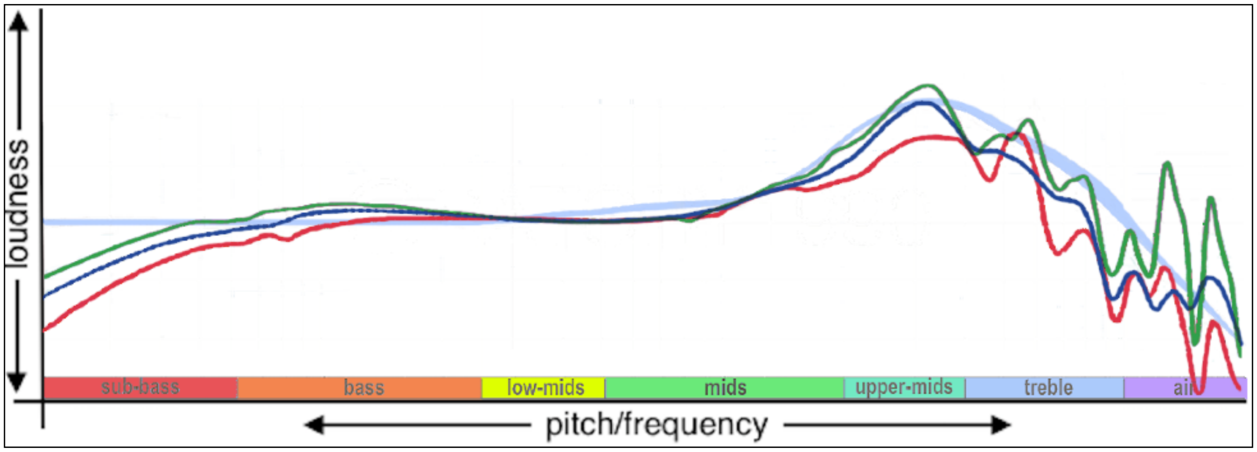


Fig. 15: Sennheiser HD 600, HD 650, HD 660S and HORN (source: HeadPhoneDatabase.com)

We see the progression toward an ever-lower ear gain peak. Similarly with Focal's two neutral-leaning models:

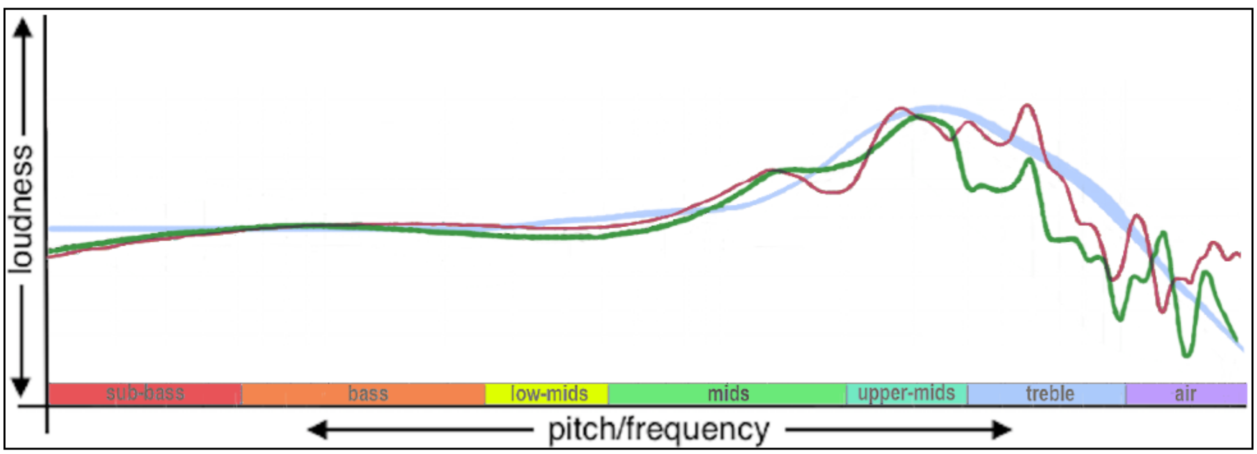


Fig. 16: Focal Clear, Utopia and HORN (source: HeadPhoneDatabase.com)

Same idea. And some of Focal's other premium headphones have even less ear gain.

Let's pursue this a little further. For Fig. 17, below, I took the average of the frequency responses of 50 of the most "neutral" headphones I could find, but including those with a Harman-like bass elevation (marked with an asterisk). Namely:

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

- 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)

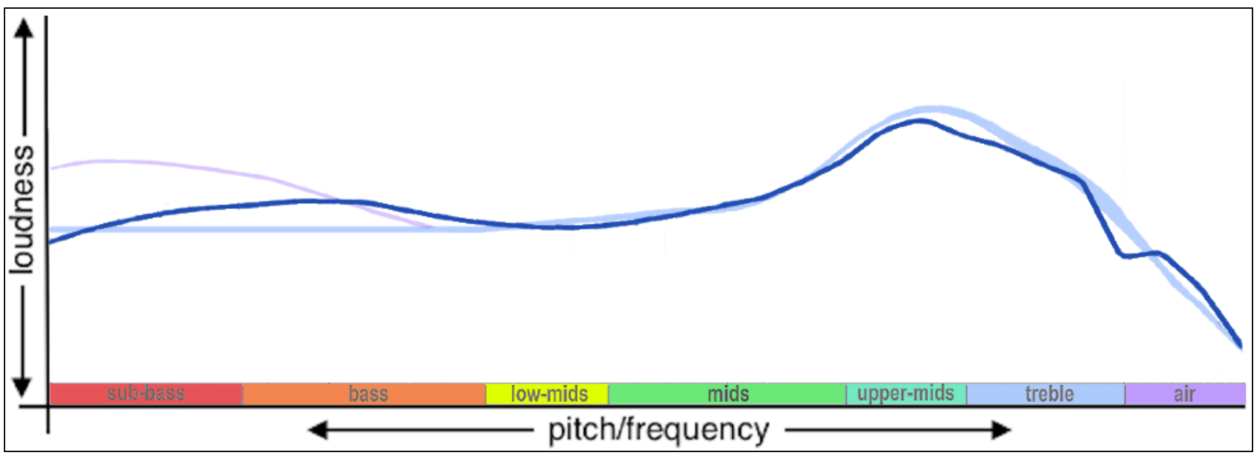


Fig. 17: average frequency response of 50 neutral headphones plus HORN and Harman

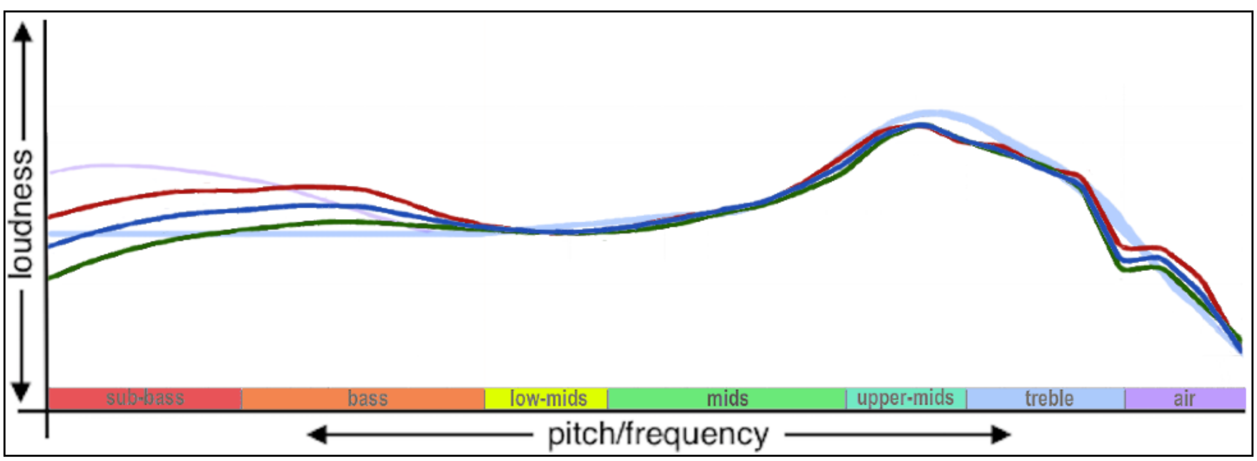


Fig. 18: average of all 50, average of 26 Harman-like, average of 24 neutral-leaning

Forgive me for slipping into full geek mode for a minute: Looking at the green line total average, with an average ear gain peak at 9 decibel, we can see that manufacturers are increasingly putting their money on a significant 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 higher ear gain peak of the 2018 Harman (and therefore the Oratory) target. I suspect the undershoot of the Harman target ear gain we see in Fig. 17 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.

One thing that's interesting about Fig. 18 is the near exact match between the average of all three curves in the mid-range and in the treble except the highest (air) octave. It's also interesting that the average bass of the Harman-like headphones barely reaches 4 decibels, compared to the 6 decibels of the target.

In any case, 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 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.
- For a manufacturer designing a new model the standard Harman 2018 target would be a safe bet — if you can get the high frequencies right. Or you could play it safe with the 50 headphone average curve.

- For personal use where maximum accuracy is essential, you need to have your own head-related transfer function measured using insert microphones.
- 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 or similar, 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.

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 large 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:

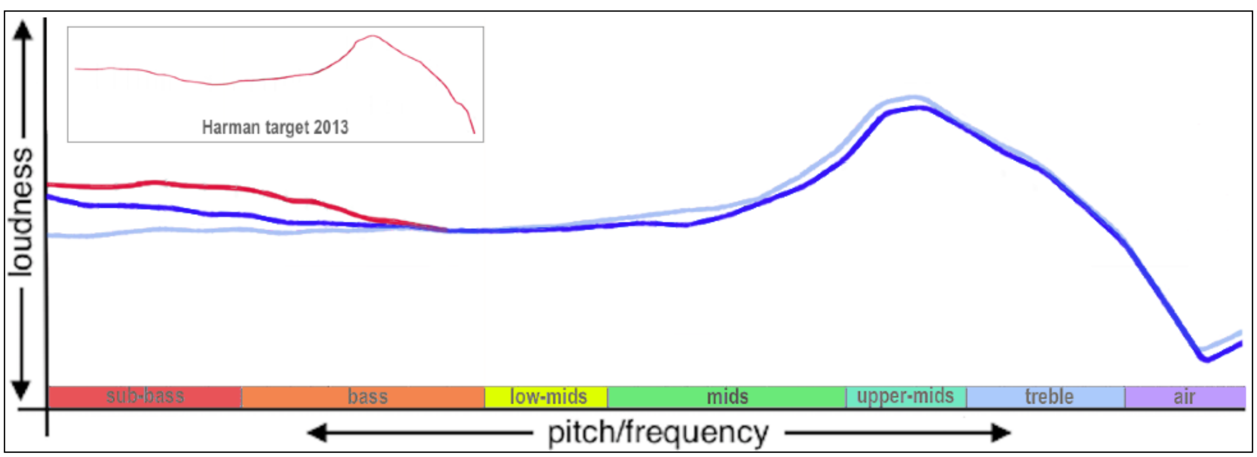


Fig. A1: the 2013 Harman target bass boost (red) combined with a 1 decibel/octave room gain applied to the linear speaker curve (blue) and compared to the Fig. 4 curve (pale blue)

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 pretty familiar with making sense of frequency response graphs as presented in this document or already were. 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.

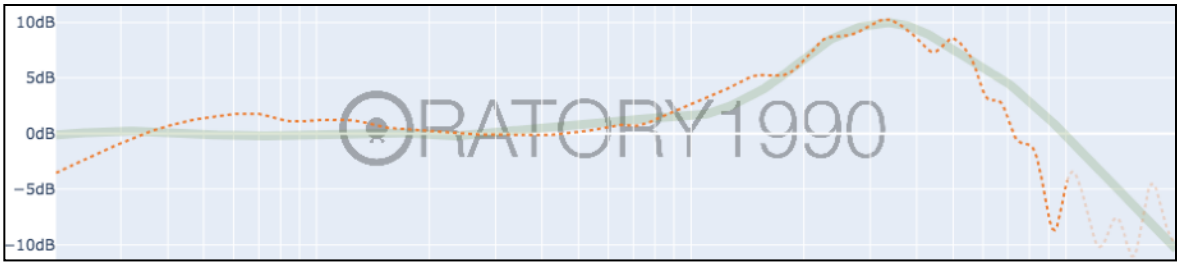


Fig. B1: headphonesdatabase.com raw data graph for Sennheiser PC38X

Fig. B1 shows the raw data for Sennheiser's latest gaming headphone.)

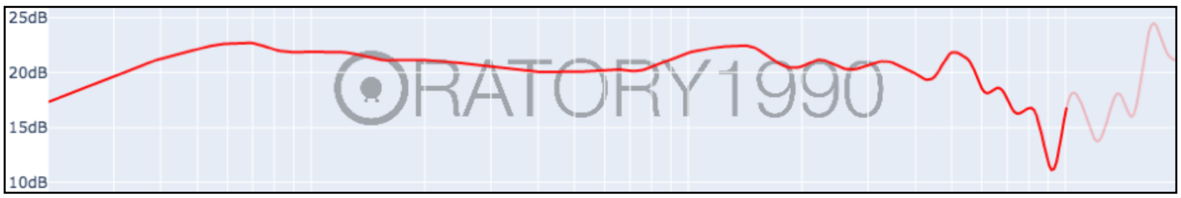


Fig. B2: headphonesdatabase.com compensated data graph for Sennheiser PC38X

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:

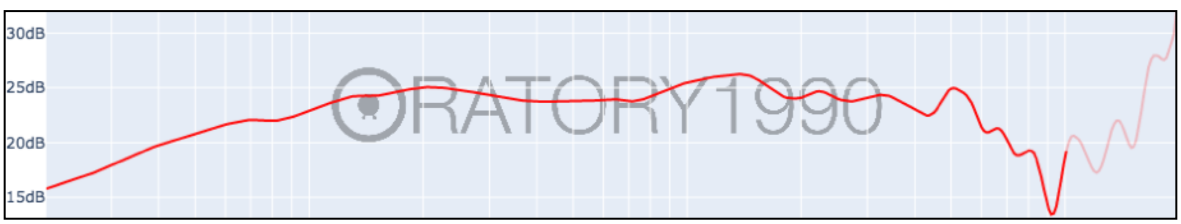


Fig. B3: headphonesdatabase.com compensated data graph for Sennheiser PC38X

… or even a diffuse field curve:

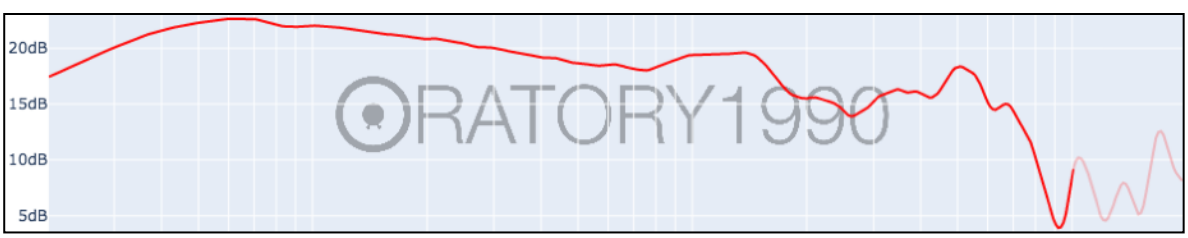


Fig. B4: headphonesdatabase.com compensated data graph for Sennheiser PC38X

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. 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 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: further reading

Some source material and further reading/viewing:

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.

Appendix D: technical versions of key graphs

Finally, 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:

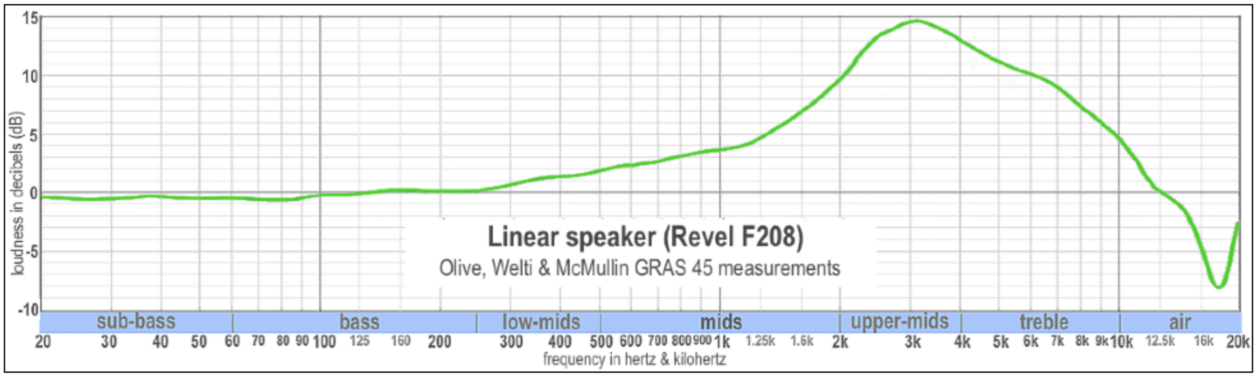


Fig. 2a: flat speakers measured at the eardrum (source: Jaakko Pasanen/AutoEQ)

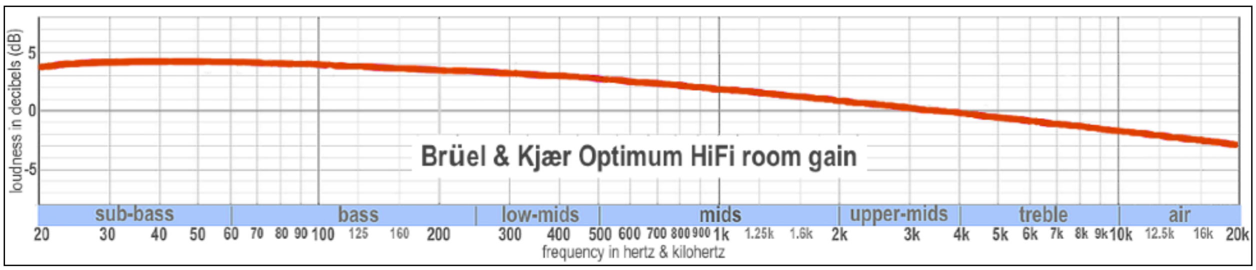


Fig. 3a: room gain frequency response (source: Brüel & Kjær)

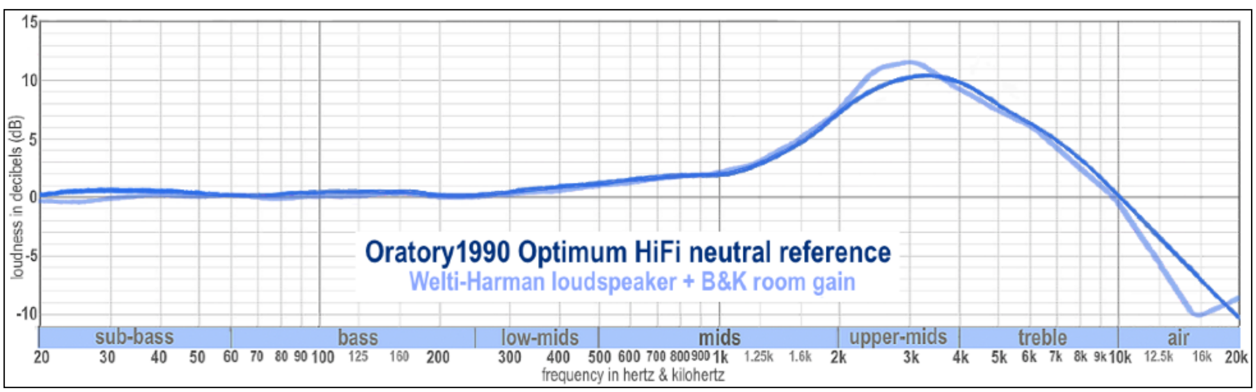


Fig. 4a+Fig.5a: Oratory Optimum HiFi and Welti-Harman+B&K room gain

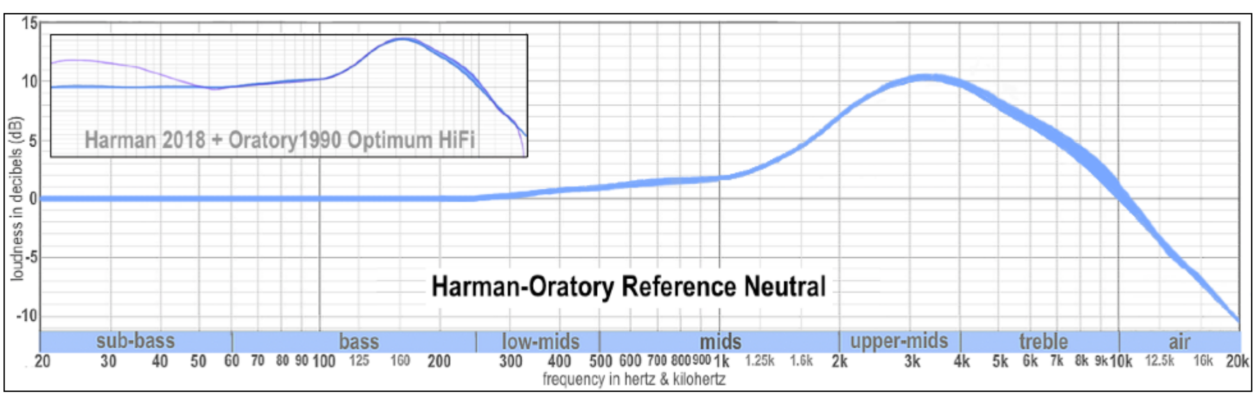


Fig. 7a: HORN

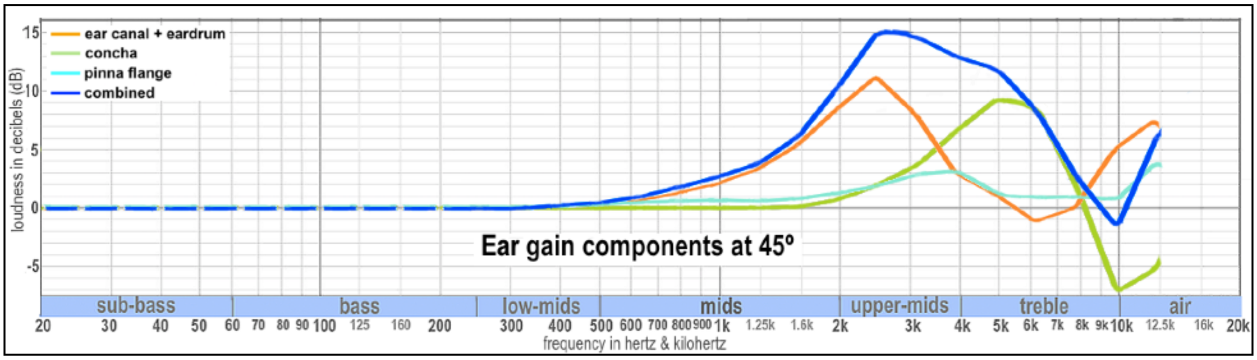


Fig. 9a: contribution to ear gain from ear regions (source: InnerFidelity)

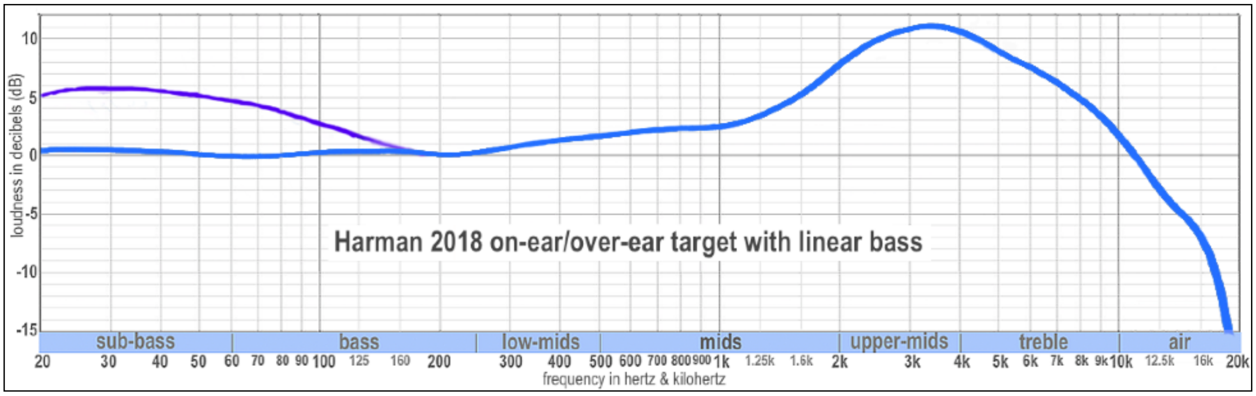


Fig. 14a: Harman target + Harman linear (source: Jaakko Pasanen/AutoEQ)

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):

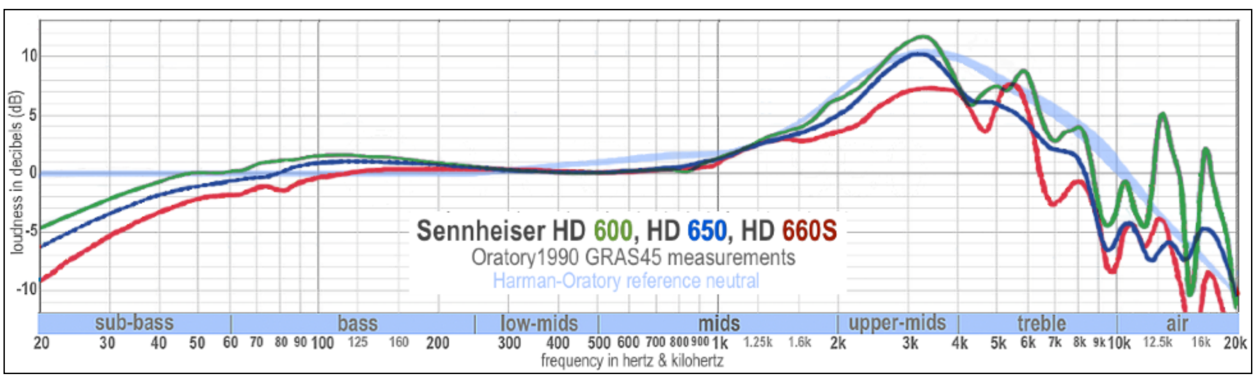


Fig. 15a: Sennheiser HD 600, HD 650, HD 660S and HORN

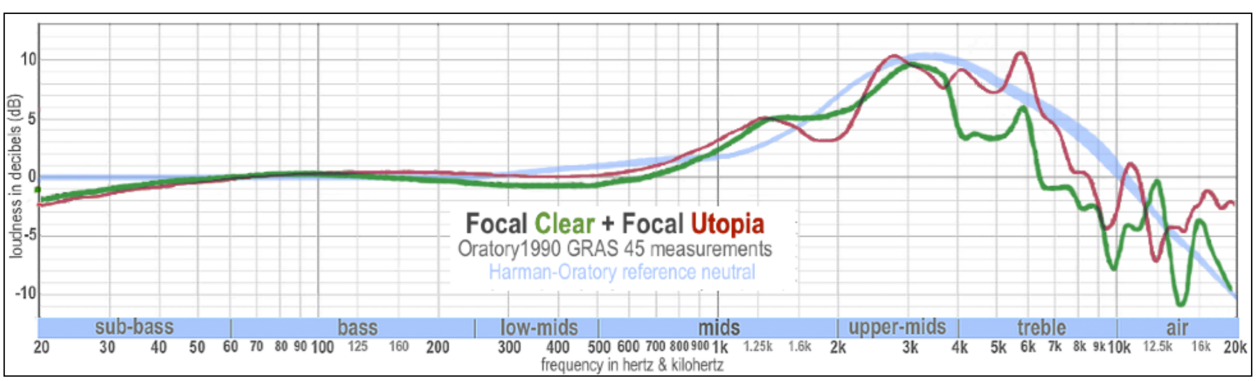


Fig. 16a: Focal Clear, Utopia and HORN

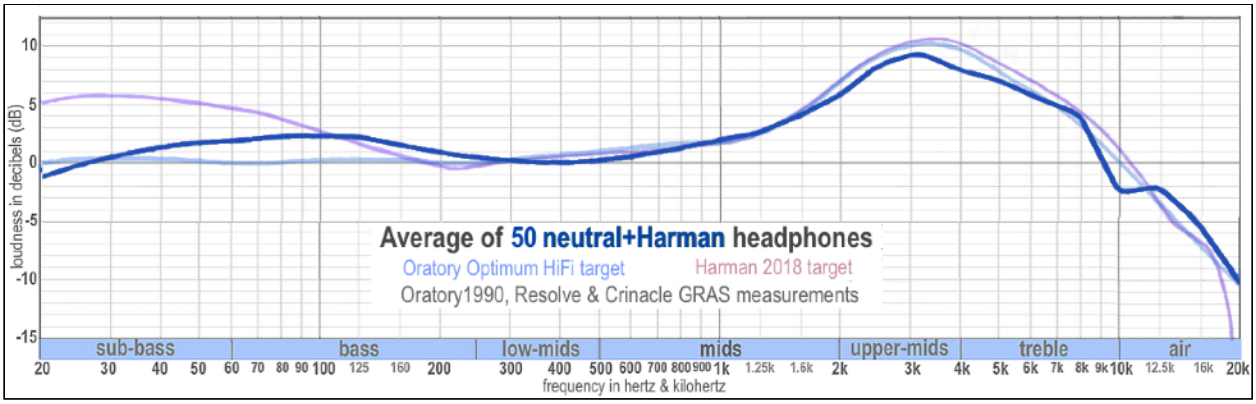


Fig. 17a: average freq. response of 30 neutral headphones, Oratory Optimum HiFi and Harman

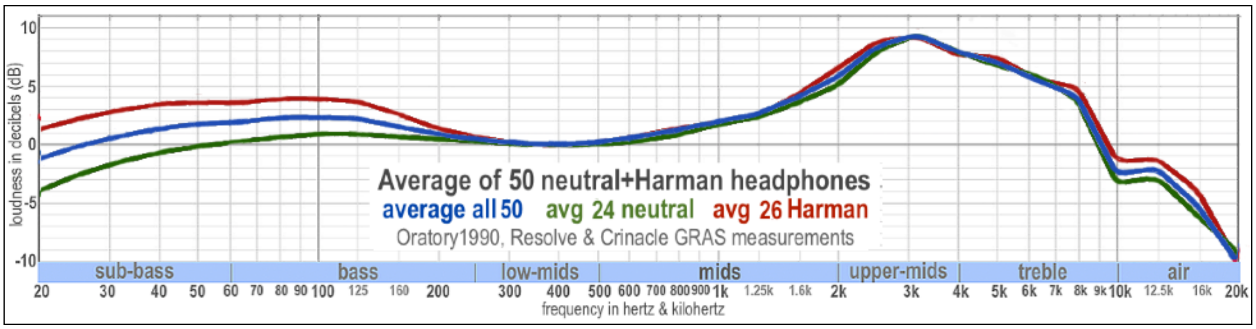


Fig. 18a: average of all 50, average of 26 Harman-like, average of 24 neutral-leaning

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

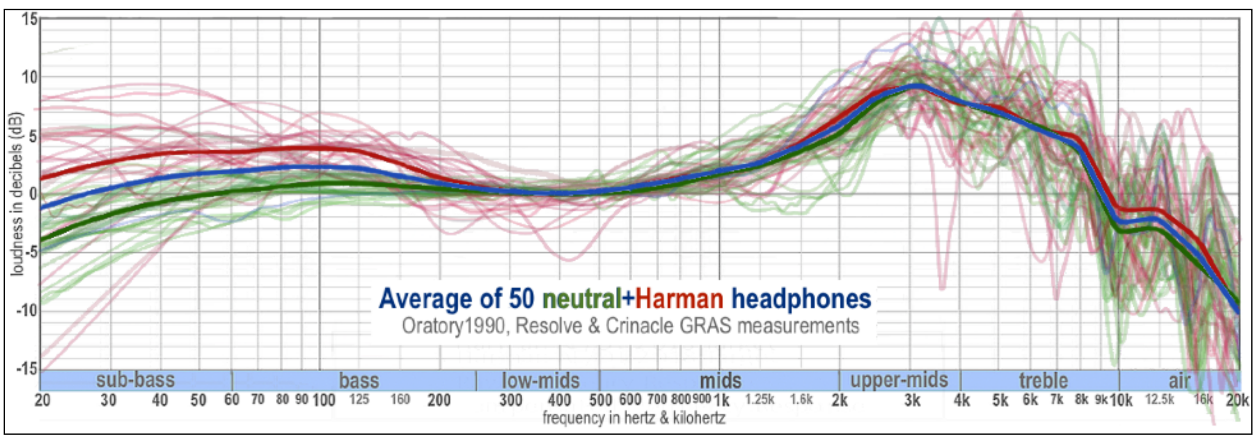


Fig. C1: average of all 50 plus actual measurements of neutral + Harman headphones

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