What's the quietest sound a human can hear? (A.k.a. "Why Omega-3 fatty acids might not cure dyslexia")

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This question comes up on AskScience quite often, and it's a great advert for curiosity-driven science. A seemingly simple and innocuous thread, tugging on it reveals not only an amazing answer, but takes us through 81 years of auditory science, 154 years of experimental psychology, and leaves us, quite unexpectedly, shouting at a press cutting from The Guardian newspaper.

The Answer

Sound intensity is typically measured in decibels (dB_{SPL}), where 20 dB_{SPL} is a soft whisper, and 100 dB_{SPL} is a pneumatic drill. The quietest sound a human can hear is 0 dB_{SPL}. That might not sound all that amazing, but bear in mind that to hear is to detect vibrations of the eardrum, caused by pressure waves in the air. Zero dB_{SPL} corresponds to a pressure wave of 0.000002 Pascals, which causes the eardrum to vibrate by approximately 10^{-8} mm. To put that in context, 0.000002 Pascals is less than a billionth of the ambient pressure in the air around us, and 10^{-8} mm is smaller than the diameter of a hydrogen atom! That we can detect such minute changes in our environment reflects what a staggering feat of engineering the human auditory system is. In fact, we wouldn't want our auditory system to be much more sensitive, since then we would constantly hear the hum of atoms vibrating in the air. Question answered. Now, to complicate matters...

The quietest sound a human can hear is <u>not</u> 0 dB$_{SPL}$

So far I have given you the answer that you can get from Google, but it is only part of the story. Actually, the limit of human hearing often isn't 0 dB$_{SPL}$, for three main reasons.

1. The threshold of 0 dB$_{SPL}$ is only an average. Some people are actually slightly more sensitive than this, while older people (and smokers) tend to be considerably less sensitive.

2. The threshold of 0 dB$_{SPL}$ only applies to a 1 kHz pure tone. Ok, this is bit of a technical point, but an important one. It turns out that our ability to hear varies with the frequency (i.e., the 'pitch') of the incoming sound wave. Following a venerable tradition in auditory science, when I made my claim of acoustic excellence I was assuming that we were listening to a 1 kHz pure tone (think: The Pips on the BBC, or the buzz of a mosquito). However, as Figure 1 shows, our hearing is actually much less sensitive at frequencies above and below 1 kHz.. For example, at a deep bass of 0.08 kHz, the minimum detectable sound pressure increases 1,000-fold, and by the 'only dogs and teenagers' region of 20 kHz, the human ear can only detect changes in sound pressures ten trillion times greater. On the other hand, you can also see in Figure 1 that our hearing is slightly *more* sensitive to frequencies just above 1 kHz, where thresholds can be as low as −9 dB$_{SPL}$!

3. The threshold of 0 dB$_{SPL}$ isn't actually strictly true at 1 kHz either. If you look very closely at Figure 1, you will see that the average hearing threshold at 1 kHz is actually slightly higher than 0 dB$_{SPL}$. Now this is actually extremely weird because, to cut a long story short[1], 0 dB$_{SPL}$ is actually *defined* as 'the smallest sound pressure that the average normal-hearing adult can detect at 1 kHz'. As we saw earlier, this value is 0.000002 Pascals. Now this should make it tautologically true that our hearing threshold at 1 kHz equals 0 dB$_{SPL}$. But it turns out that while the value of 0.000002 remains the 'official' answer (and thus the definition of 0 dB$_{SPL}$), it is most likely wrong. That value was reported by Fletcher and Munson in 1933, and their original paper is freely available online if you search on Google Scholar. However, the data in Figure 1 are *new measurements* that were published in 2003. These measurements were made in a host of laboratories across the world, and the results differed in a number of ways from Fletcher and Munson's original measurements. Thus, hearing was found to be slightly poorer at 1 kHz, and, more worrying still, there were actually some quite large differences at lower and higher frequencies. For example, observers in 2003 exhibited more sensitivity to low frequencies than observers in 1933, but exhibited less sensitivity at higher frequencies. Now we can't say for sure that these measurements are more accurate or precise than Fletcher and Munson's (in fact, some influential measurements made in 1956 by Robinson and Dadson have been shown to be much *less* accurate than those made originally by Fletcher and Munson in 1933). However, they are certainly different. And this brings us nicely to the next chapter of this saga. . .

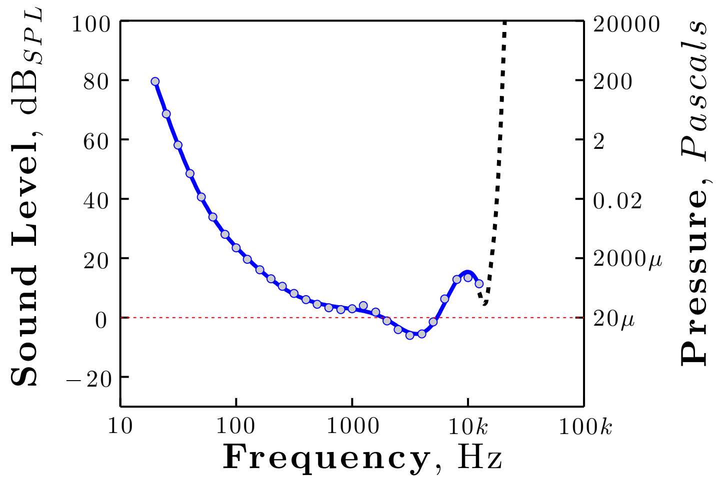

Fig. 1: Hearing threshold as a function of frequency (lower is better). Interestingly, the range of peak hearing ability corresponds roughly to where a large proportion of the acoustic energy is found in speech. But did hearing evolve to fit out speech, or *vice versa*?

To err is human

Why is it that humans in 2003 seemed have different hearing to humans in 1933? The most likely answer is rather a dull one: measurement error. To see what makes this so plausible an explanation, consider how the curve in Figure 1 was derived. That is, how do we measure what the smallest sound is that a person can hear? This question, and those like it, spawned a whole discipline called 'psychophysics' when Gustav Fechner first asked them in 1860, and the answer has remained largely unchanged since. We do the only thing we can do: we vary the intensity of the sound until the observer can only just hear it, and we define that value as the observer's 'threshold'. Thus, Figure 2(top) shows actual data from an observer performing a sound-detection task. In that case, things went well. Above a certain level, the observer consistently heard the sound. Below this level, they consistently failed to hear the sound. We can therefore reasonably conclude that this cut-off level constitutes their 'true' threshold of hearing.

However, often things are a little messier. Thus, it is not unusual to see data like that in Figure 2(bottom). These data actually come from the self-same person as before, tested again ten minutes later. In this case, something went wrong, and the result was a much higher threshold. In fact, the result was almost indicative of a mild hearing loss. Had they temporarily forgotten how to hear? No, of course not. They probably got distracted, or bored, or gave a series of incorrect answers either by mistake, design, or misfortune. In fact, luck is often a surprisingly important factor in such tests, since when operating at their limit our sensory systems are surprisingly probabilistic (i.e., you may hear a sound 80% of the time, and not hear the same sound 20% of the time). The point is that there are lots of ways that you could score badly on such a test, only one of which involves having poorer hearing. And equally, there are

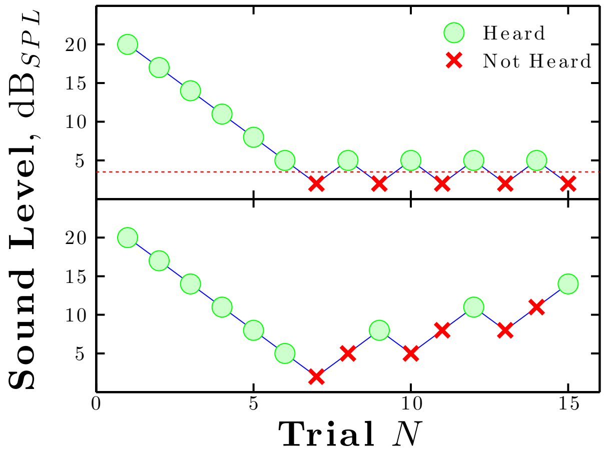

Fig. 2: A 'good' (top) and 'bad' (bottom) hearing test; both in the same individual.

many spurious reasons why performance may subsequently improve[2], and why performance may even exceed 'true' ability. Now all this hopefully seems rather obvious. But the fact is that it isn't widely appreciated. People don't realize what a challenge it is to measure something as simple as 'what's the quietest sound you can hear?' In fact, avoiding these 'bad' measurements, and finding ways to guarantee 'good' measurements is actually a huge part of my day job as a scientist. And although it may seem benign, the misplaced trust we put in the 'scientific method' to always yield that right answer can have some very real consequences in our day-to-day lives...

One morning in November

Finally then, this brings us, along with our newfound distrust of psychophysics, to Thursday 6th November. That morning I received a letter from my mum. In it, there was a press cutting from The Guardian, containing the article "Fishy Business" (entitled seemingly without irony). The article described some intriguing work by an emeritus Professor at Oxford, in which dyslexic children were given an Omega-3 fatty acid supplement. It was suggested that this might promote neural development, and that this might somehow improve children's ability to track rapid fluctuations in sounds. Cited as evidence was pilot work in which children given an Omega-3-extract showed improved reading ability.

Now, let's be clear, I don't mean to single this work out for criticism. It was only preliminary, pilot work, and the authors were keen to stress as much. Moreover, the journalist didn't report the exact methods used to measure reading ability. However, it doesn't take a huge leap of faith to assume that the scientists used some form of psychophysical procedure not dissimilar to the one described above, and that this was done in a bit of a hurry because, after all, they were dealing with children (and, specifically, children with suspected attention difficulties). Now bear in mind, we know there are lots of ways that people may randomly perform better or worse on a test, and so with a small group of noisy subjects, spurious trends will often emerge by chance. The question with all such stories therefore becomes, what is more likely: that the fish-oil tablets somehow affected the human brain in a manner so profound as to cause a measurable improvement in cognitive function (yet so subtle, that nobody has noticed this phenomenon before)? Or that this was simply a fluke: a chance variation in performance that led to an apparent improvement?

The answer with such stories is almost invariably the latter. This doesn't mean that the claim is definitely *not* true, just that it needs treating with healthy scepticism. Based on these 'green shoots', it may well be that the potential (albeit unlikely) rewards of treating dyslexia with fish oil justifies the cost of further investigation. But the key point is that this. Next time you see something that claims to increase your intelligence, enhance your vision, relieve your dyslexia, or reduce your ADHD, pause to consider how they might have gone about measuring such changes, and then remember just how hard it is to measure something as simple as the quietest sound a human can hear.

Notes

[1]Ok, so time for the long story – what *are* decibels? The key point is that a 'decibel' value on its own is nothing, is literally meaningless. This is because a decibel is, fundamentally, a ratio. A ratio of some current quantity, x, to some predefined reference quantity, R. A dB value of less than zero means that x is smaller than the reference, a value above zero means that x is bigger than the reference. So what is the reference? What is R? Well therein lies the rub, it could be anything! People can, and do, define R differently depending on what it is they happen to be interested in. For 'decibels' to mean anything, the reference level must therefore be stated. Typically when it comes to sound, the reference is 'the smallest sound that the average normal-hearing adult can detect at 1 kHz', which historically was measured as being $R = 0.000002$. By convention, measurements made using this reference are denoted by the subscript SPL (Sound Pressure Level), so that the reader knows how to interpret the meaning of the value. So, pro tip for parties: next time somebody says that something is 'x decibels loud', immediately stop them and demand to know what reference level they are using (do they mean dB_{SPL}?). For bonus marks also demand to know the frequency of the sound they were measuring (i.e., since, by inspection of Figure 1, 100 dB_{SPL} might be quite impressive at 1 kHz, but barely audible at 18 kHz), and the distance at which the measurement was taken (i.e., since sound pressure varies inversely with distance, such that even a whisper might be 100 dB_{SPL} if you get close enough). To really seal the deal, you might then point out that, anyway, dB_{SPL} is actually a measure of physical sound intensity, not of perceived loudness. Best. Party. Ever. Formally, decibels are defined as: $dB = 10log_{10}(x/R)$. Thus, $dB_{SPL} = 10log_{10}(P/0.000002)$, where P is the magnitude of the current sound, measured in terms of change in atmospheric pressure. For mathematically inclined readers, note that the use of a logarithm was chosen to reflect how our sensitivity to changes in loudness varies with baseline intensity. This reveals something absolutely fundamental about the mammalian nervous system, and how it is designed to detect relative changes in the environment rather than absolute quantities (hint: consider the difference between $P = 1$ and 2, versus $P =$ 50 and 100). For anybody who is still reading – have some pub quiz trivia as a reward. Decibels were originally called 'Transmission Units'; the name decibels was coined in 1928 by scientists at Bell Telephone Laboratories (home of 8 Nobel Prizes, Unix, C, C++, lasers, and the transistor), in honour of Alexander Graham Bell.

[2]Indeed, if the previous, poorer threshold really was due to bad luck then simply repeating the test should, more often than not, result in an improvement. This effect, known as Regression To The Mean lies at the heart of a worrying number of studies in which initially poor-performers magically improve after some completely impotent 'cure' has been administered. The trick is to consider what happened to the initially really good-performers. If the variations is performance were just down to random chance then the fluky over-achievers should actually have gotten worse second time round. Other considerations, like practice-effects on tests, can cause both under- and over-achievers to improve.

References

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