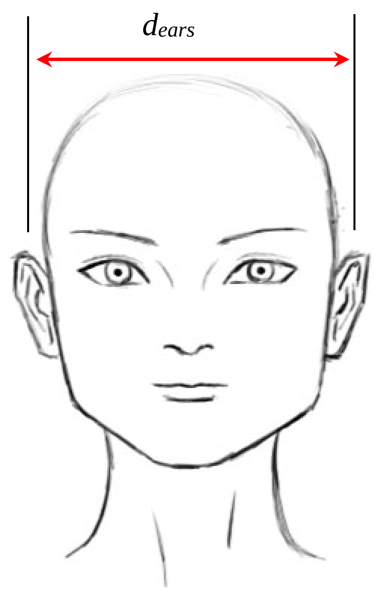
At frequencies above $f > 4000\ Hz$, sound localization is increasingly due to the perceived sound intensity level ***difference*** of both ears – the head casts a "shadow" on the away-side ear for increasingly high frequency sounds. At low frequencies, this effect disappears due to ***diffraction*** of the sound wave around the head… At frequencies of $f \sim 1000\ Hz$, the sound intensity level is only ~ 8 *dB* greater for the ear ***nearest*** the source, whereas at frequencies of $f \sim 10\ KHz$, the sound intensity level difference can often be ~ 30 *dB*.



The human ears are separated by a typical distance of d_{ears} ~ 6" (= 1/2 foot, or ~ 15 *cm* = 0.15 *m*).

When the ear-ear separation distance is comparable to the wavelength of a sound, the corresponding (maximum) arrival time difference is $\Delta t = d_{ears}/v \sim \lambda/v = \tau_{osc} = 1/f$.

Thus, for $\lambda \sim d_{ears} \sim 0.15\,m$ and $v = 343\,m/s$ then $\Delta t \sim 0.15/343 = 0.44\,ms$ or: $f = 1/\tau_{osc} = 1/\Delta t \simeq 2300\,Hz$.

For frequencies higher than this, it becomes increasingly difficult for us to localize sound sources… The folds/creases in the pinna of our outer ears are there to aid/enhance localization of sounds in this higher frequency region!

It is also true that when $\lambda \gg d_{ear}$ (*i.e.* very low frequencies) we also have difficulties in localizing sounds – again due to ***diffraction*** of low frequency sound waves around our heads!

Practically, studies (we and others have carried out) show that we humans can accurately localize sounds in the frequency range of $100\ Hz \le f \le 1000\ Hz$.

Compare these results to our (very poor!) ability to localize sounds in ***water***, where $v_{H_2O} \simeq 1500\,m/s$. The arrival time difference of sound waves (left – right) ears in water is $\Delta t_{H_2O}^{L-R} \simeq (343/1500)\Delta t_{air}^{L-R} \sim 0.2\Delta t_{air}^{L-R} \Rightarrow$ 5× less in water! $\Rightarrow$ much harder for humans to localize sounds underwater than in air! However, many fish & other marine creatures (*e.g.* dolpins) can easily (and accurately) localize sounds underwater – because their hearing has been optimized for propagation of sound waves in water with speed $v_{H_2O} \simeq 1500\,m/s$!!!

Because we have lived in an air environment for millions of years, our human hearing has been specifically optimized for propagation of sound waves in air with speed $v_{air} \simeq 343\,m/s$!!!

Imagine how well we'd be able to localize sounds if we instead lived *e.g.* in a helium atmosphere, where v_{He} ~ 970 *m/s* ~ 3×v_{air} or *e.g.* instead lived in an atmosphere of sulphur hexafluoride (SF_6), where v_{SF6} ~ 150 ~ 0.44×v_{air} *m/s* !!!