

Comparison between the eye and the ear as imaging systems

CAUTION: This article may include pseudoscience.

"Write about 200 words comparing the ears (as an acoustical imaging system) to the eyes (as an optical imaging system). In particular, pay attention to the issues of frequency, intensity, phase, positioning and analysis by the brain. You will need to think about this for yourself; the answer is not easily found in books. Reference any sources you use."

The ear

The ear detects sound (vibrations) via an array of stiff hairs in the cochlea. The variable stiffness results in different resonant frequencies for different hairs^A (lower frequencies further along the cochlea^B), allowing the audio frequency spectrum to be detected^C by the auditory nerve. As the sound is detected via the amplitudes of vibration of an array of driven, damped harmonic oscillators, phase information is lost. One might assume that the ability of the brain to determine spatial position of a sound source, due to short time differences between the signals received by each ear would suggest some ability to measure phase differences between the signals received from each ear, however this may be disproven by listening to two synthesised sounds (e.g. sine waves) with a phase difference. The positional information comes from the delay in intensity changes at each ear, due to the sound having to travel a longer distance to one ear than the other. Additionally, oscillating intensity envelopes with frequencies below the range that the cochlea can detect may be detected by the brain as "beating" or "tremolo". When both ears hear a slowly "beating" sound, with a phase difference between the beating received by each ear, the brain may incorrectly deduce a position from the intensity gradient difference.

The brain then identifies harmonic patterns. An excellent example of this is the "missing fundamental illusion", where a lower note is perceived than the one presented, due to the brain "expecting" a fundamental that is not present^D. "Perfect 5th" chords, used extensively in classical and rock music utilise this effect to create the illusion of "depth"^{*}. Similarly, the "Shepard scale" uses this to create the illusion of an ever-increasing (or decreasing) scale^E.

In summary, the ear produces a frequency-domain representation of received sounds (see "continuous wavelet transform"), preserving frequency and intensity information while discarding phase. Positional information comes from millisecond-scale time differences between intensity envelopes detected by each ear.

* This illusion uses fact that an increase by a "perfect 5th" in musical terms equates to a (non-integral) frequency multiplication by a factor of 1.5 in scientific terms. As the brain does not expect non-integral harmonics (slight abuse of the word "harmonic" there), it assumes that instead of the root and 5th being "harmonics" 1 and 1.5, they must be harmonics 2 and 3 – resulting in a lower root note being perceived, with half the frequency of the root note of the chord. Heavy metal extends this by addition of the octave, with double the frequency of the root note. The presence of the "1.5 harmonic" (i.e. the 5th) prevents the brain from recognising the octave and the root as 2nd and 1st harmonics respectively, and instead causes the perception of a root with half the frequency of the actual root, and a harmonic spectrum consisting of root, 2nd harmonic and 3rd harmonic. The ringing of the actual root note and the octave note creates the grinding "machine" sound that characterises heavy-metal backing music, while the perceived false fundamental adds "depth" and "bass" to the sound.

^A "Wikipedia: Cochlea", http://en.wikipedia.org/wiki/Cochlea#Detailed_anatomy obtained 09-03-2011

^B NEUROSCIENCE: Exploring the Brain (Third Edition), MF Bear, BW Connors, MA Paradiso, ISBN: 978-0-7817-6003-4, pp. 351-360

^C "Physiology of the ear", Anthony F. Jahn, Joseph Santos-Sacchi

^D "Pitch: neural coding and perception", I Winter (2005), Ch. 4, pp. 99, ISBN: 978-0-387-28958-8

^E "Circularity in Judgments of Relative Pitch", RN Shepard, *J. Acoust. Soc. Am.* 36, 2346 (1964)

The eye

Somewhat less is known about visual processing, possibly due to the greater amount of information that is processed – the eye detects intensity and colour across two spatial and one temporal dimension, compared to the ear which detects just intensity [and frequency, depending on the model used] over a temporal dimension. The eye contains four types of photoreceptor^A - colour “cones” and monochrome “rods” (peaking in the blue range). We will just consider the over-all intensity field reported by one type of receptor.

Two of the many competing views of visual processing arise from two different views of how large neural networks process information. Karl Pribram (and David Bohm) hypothesised a “holographic” effect of the vast inter-connectedness of neural networks, resulting in the brain processing the Fourier transform of an image, rather than a spatial representation^B. In Pribram’s model, the brain processes the Fourier transform of an image, containing intensities of (spatial) frequencies and their phase components. In such a model, phase information would encode the spatial position of some detail within an image, and harmonic patterns would identify the type of detail (similar to the harmonic pattern matching described for auditory processing).

In summary, and assuming a “holonomic brain” model (for Pribram’s theory), the eye provides intensity information, in frequency domain, also preserving phase which is necessary for derivation of lateral positional information.

^A NEUROSCIENCE: Exploring the Brain (Third Edition), MF Bear, BW Connors, MA Paradiso, ISBN: 978-0-7817-6003-4, pp. 296-297

Due to the existence of two different varieties of the red pigment, which is encoded on the X chromosome, some women may have both types of red cone, in addition to the usual green, blue cones – giving tetrachromatic vision.

^B “Comparison between Karl Pribram’s ‘Holographic Brain Theory’ and more conventional models of neuronal computation”, Chapter 4, Jeff Prideaux, <http://www.acsa2000.net/bcngroup/jponkp/#chap4> obtained 09-03-2011

Conclusion

It is reasonable to assume that both visual and auditory information is processed in frequency-domain. While both ears are used to derive positional information, and phase information is not preserved by the auditory transducer (the cochlea), the eye does preserve (spatial) phase information, which is used to generate positional information.