Neurobiology and Human/Animal Behaviour
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problem set #4 solutions

1. A decibel is a tenth of a Bel. A Bel is a relative measure of sound intensity equal to the logarithm of the ratio of the power levels of the two sounds being compared: B = $\log(P_1/P_2)$
Since the intensity range of human hearing spans only about ten Bels, sound levels are more commonly expressed in terms of decibels: dB = $10 \log(P_1/P_2)$

Note that the Bel and the decibel express relative loudness. Absolute loudness is often measured as the root mean squared pressure exerted by the sound waves. Since it would be convenient to be able to measure absolute loudness in dB, but dB are a relative measure, we define a standard pressure of 20μN m^{-2} as zero decibels of sound pressure level (0 dB SPL), and measure all other pressure levels relative to this standard. Since power increases as the square of pressure, the ratio inside the logarithm must be squared – or, equivalently, a factor of two must be included outside the logarithm: dB SPL = $10 \log((\text{pressure}/20\mu\mathrm{Nm}^{-2})^2) = 20 \log(\text{pressure}/20\mu\mathrm{Nm}^{-2})$

2. The middle ear is an ingenious system that achieves nearly 50% power transfer (the theoretical maximum) between ear and endolymph. Without this mechanism for impedance matching, most of the sound energy would be reflected back out from the tympanic membrane.

3. The stapes presses on the oval window, displacing endolymph along the scala vestibuli, which communicates with the scala tympani via the low-pass pressure relief of the helicotrema. The pressure waves conducted through this system are relieved by movement of the round window. The scala media is sandwiched between the basilar membrane (where transduction in hair cells takes place) and Reissner's membrane.

4. Inner hair cells on the basilar membrane contain cilia that project into the endolymph and are moved by passing sound waves. Actin filaments link these hairs mechanically to ion channels, which open and close when the hairs sway.

5. Frequency masking is the ability of a high-intensity sound to reduce the apparent intensity of a lower-intensity sound at a slightly different frequency.

If the intensity difference is great enough, the lower-intensity sound may be rendered completely inaudible.

6. The major difference between the MAF and the MAP occurs around 4 kHz, a band of frequencies within which most of the information in speech is carried. The difference between the MAF and the MAP arises because of resonant properties of the pinna and the auditory canal.

7. Low-frequency sound localisation is a lovely example of what can be done using population coding. Even though none of the individual neurons by itself can code the precise inter-aural time delay, the locus of maximal activation across the *population* of neurons can represent this information.

8. Inter-aural phase lag is computed in the superior olive, probably by interneurons that take input from slowly conducting axons that act as delay lines from each ear. Since these delay lines are antiparallel to each other, signals from each ear will maximally coincide at only one point along the length of the delay lines, and depolarisation of the interneurons will be maximal at this point.

9. Since it takes time for a neuron to depolarise and initiate an action potential, phase information cannot be preserved in signals with very short periods (high frequencies).

10. The neural coding of sound passes from the cochlear nucleus to the superior olive, to the inferior colliculus, to the medial geniculate nucleus of the thalamus, to primary auditory cortex in the superior temporal gyrus.

11. MP3 encoding uses the property of frequency masking in order to decide how much resolution must be preserved and how much can be discarded at each particular frequency. As long as the amplitude of the square-wave digitisation artefact is below the masking threshold, it won't be heard.