3.9.2.4: Animal Hearing

> **Note**
>
> Much of the information about animal perception in this chapter and in Chapters 14 and 16 comes from the excellent book *Engineering Animals: How Life Works* by Mark Denny and Alan McFadzean.

Many animals, including dogs, can hear frequencies in the ultrasonic range (above $20,000\text{ Hz}$). Dog whistles used to train dogs have frequencies between about $23,000\text{ Hz}$ and $54,000\text{ Hz}$ so dogs (and many other animals) can hear them but humans cannot. As mentioned in Chapter 8, humans are about the best existing species in being able to hear frequencies in the range of 1000 Hz to 5000 Hz. In this frequency range, humans and elephants can hear softer sounds than dogs and cats, who can hear better than rats, who can hear better than horses and cows. Birds and fish generally hear a much smaller range of frequencies than mammals and also do not hear softer sounds as well. Some insects hear very specific bands of frequencies, for example crickets have a hearing range for signals generated by other crickets for communication purposes but they have a different, unconnected range of hearing to detect the echolocation signals coming from bats, which are a predator.

Animal	Hearing range in Hertz
Humans	$20-20,000$
Bats	$2000-110,000$
Elephant	$16-12,000$
Fur Seal	$800-50,000$
Beluga Whale	$1000-123,000$
Sea Lion	$450-50,000$
Harp Seal	$950-65,000$
Harbor Porpoise	$550-105,000$
Killer Whale	$800-13,500$
Bottlenose Dolphin	$90-105,000$
Porpoise	$75-150,000$
Dog	$67-45,000$
Cat	$45-64,000$
Rat	$200-76,000$
Opossum	$500-64,000$
Chicken	$125-2,000$
Parakeet	$200-8,500$
Horse	$55-33,500$

Table $3.9.2.4.1$

As a rule of thumb, small animals tend to make and hear higher frequencies and larger animals are more likely to make and hear lower frequencies, although there are many exceptions as can be seen in the chart. In general the shape of the outer ear is also related to which frequency range and the direction an animal is listening to. For example rabbits have tall ear lobes which makes them more sensitive to sounds coming from a horizontal direction because their predators are mostly terrestrial. Mice, on the other hand, have rounder ears which makes them more sensitive to sounds coming from above, since birds of prey are predators for them. Elephants have very broad, flat ears which are more receptive to lower frequencies with which they communicate. Owls and some other animals can change the relative orientation of their outer ears or will move their entire heads to achieve better accuracy in determining the direction from which sounds are coming. Many animals, such as deer, have muscles that can point the pinna in different directions, enabling better predator detection (humans have atrophied versions of these same muscles but they no longer produce much motion of the ear). Further discussion of animal hearing and its use for orientation and navigation will be postponed to Chapter 16: Acoustics.

Video/audio examples:

- Article by Peter L. Tyack in *Physics Today* about Human-generated sound and marine mammals.

Summary

The ear is composed of three main parts. The shape of the outer ear gives us information about the direction sound is coming from and funnels sound into the middle ear. The middle ear overcomes the impedance mismatch between air and liquid and transmits sound to the cochlea via the ossicles. The cochlea gives us our sense of balance and turns mechanical vibrations into nerve impulses. There are two theories of hearing, the place theory and the temporal theory. Neither can account for the richness of our perception of sound such as the missing fundamental, critical bands or other interesting aural illusions. Both theories may operate but in different frequency ranges. Age related hearing loss, presbycusis, generally lowers the loudness of high frequencies as we grow older. Loud sounds can also cause either conductive or sensorineural hearing loss.

Questions on Perception:

1. What does the fundamental frequency of an instrument determine?
2. Explain the difference between subjective measures of pitch, loudness and timbre as compared to the objective measurements of fundamental frequency, sound intensity and waveform.
3. Describe the structure of the outer ear, middle ear and inner ear. What is the function of each of these sections of the ear?
4. What is the function of the pinnae?
5. What do the ossicles in the middle ear do?
6. What does the cochlea do besides turn sound into nerve impulses?
7. What are the two types of hair cells (in the cochlea) and what does each do?
8. What is the basilar membrane and what does it do?
9. What is impedance mismatch? Why is this significant in the context of the ear?
10. How does the structure of the ear overcome the impedance mismatch between the air at the eardrum and the fluid in the cochlea?
11. Explain the place theory of hearing.
12. Explain the temporal theory of hearing.
13. Why do we have two theories of hearing?
14. What is virtual pitch (missing fundamental)?
15. An ear bud for a cell phone cannot produce a low frequency, long wavelength sound wave of 50 Hz. Yet we perceive this frequency when we listen to music through an ear bud. How does this work?
16. There are two uses of the word ‘beats’ in sound. One has to do with the rhythm of the music. The other has to do with something that happens when two notes near the same frequency are played together. Explain the second use of the word ‘beats’.
17. Explain the concept of critical bands for two notes that are close together in frequency played at the same time.
18. What is dissonance? How would you demonstrate this if you had a way to make several different frequencies (like the critical band simulation)?
19. What are attack frequencies? What effect do they have on our perception of an instruments timbre?
20. What are the two main causes of hearing loss?
21. What are the two main types of hearing loss?
22. What is presbycusis, why does it happen and what are the results?
23. Which type of hearing loss can be corrected by surgery?
24. What can go wrong in the middle ear to cause hearing loss?
25. What can go wrong in the cochlea to cause hearing loss?
26. Pick two the following auditory illusions and explain them:
    a. Shepard’s illusion
    b. octave illusion

c. Deutsch's Scale Illusion
d. glissando illusion
e. McGurk effect
f. melody illusion.