Pre-Lab: Read the Pre-Lab sections of this lab assignment and go over all exercises before going to your actual assigned lab session.

Verification: When you have completed a step and want verification, simply demonstrate the step to the instructor.

Lab Report: It is only necessary to turn in a report on Sections that require you to make graphs and to give short explanations. You are asked to label the axes of your plots and include a title for every plot. If you are unsure about what is expected, ask the instructor.

1 Pre-Lab

The Pre-Lab is about **Sound localization** versus **Lateralization**.

1.1 Goal

The purpose of this lab is to demonstrate effects that can occur when two tones or complex sounds (e.g., clicks) are heard simultaneously, to demonstrate the auditory system's use of interaural time and intensity differences in localization.

The specific goals are:

1. Understanding lateralization as produced by binaural hearing through headphones.
2. Evaluation of binaural examples of the Auditory Demonstrations CD.
3. Creating Binaural Stimuli with Matlab.

1.2 Sound Localization and Lateralization.

Localization and *lateralization* — the most important benefit we derive from binaural hearing is the sense of localization of the sound source. Although some degree of localization is possible in monaural listening, binaural listening greatly enhances our ability to sense the direction of the sound source. Localization includes up-down and front-back discrimination, but most attention is focused on side-to-side discrimination or lateralization. Try this virtual surround sound example: click here with and without headphones.

When we listen with headphones, we lose front-back information, so that lateralization becomes exaggerated; the image of the source appears to switch from one side of the head to the other by moving "through the head", or the sound source appears to be "in the head."

Low frequency sounds are lateralized mainly on the basis of interaural time difference, whereas high frequency sounds are lateralized mainly on the basis of interaural intensity differences.

1.3 Are binaural cues alone, enough to localize sound.

Have a look at this "Fox hunting by sound localization video".

This small extract of the "Yellowstone" nature program from the BBC shows a fox, which is using his sound localization ability to hunt prey animals that are concealed under a cover of snow. This clearly shows that not only owls can hunt prey by use of sound localization cues alone.

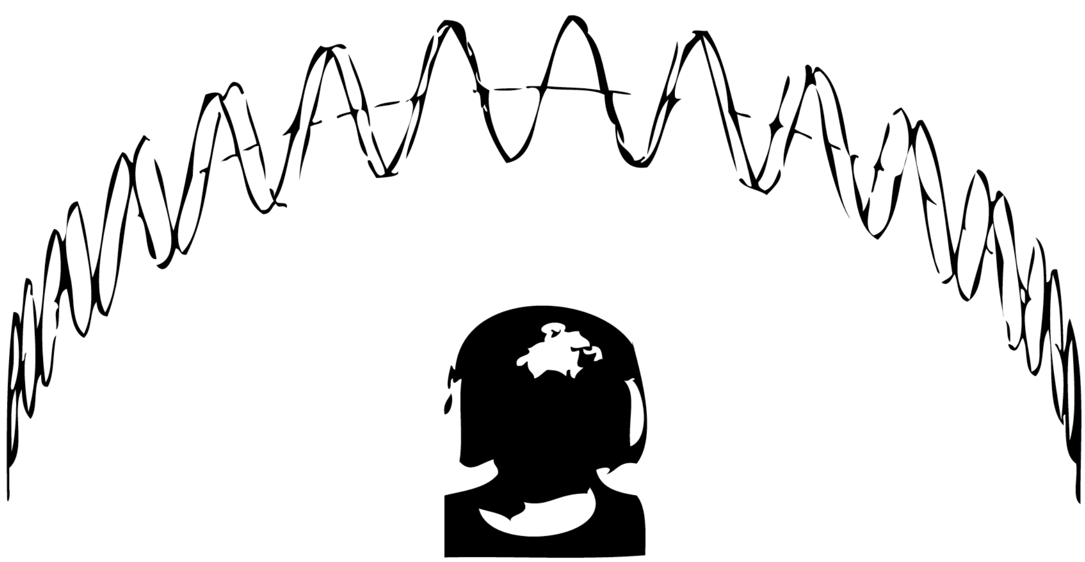
Owls have complete spatial maps of sound space Azimuth and Elevation (in head coordinates) by means of binaural cues alone. The fox lacks such a map. How do you think that the Fox solves this problem?

1.4 (Binaural) Beats.

Beats are an important contributor to the sensation of dissonance in music, and form an invaluable perceptual tool for the tuning of musical instruments.

Primary beats: If two pure tones have slightly different frequencies $f1$ and $f2$, where $f2 = f1 + \Delta f$, the phase difference, p1-p2, changes continuously with time. The amplitude of the resultant tone varies between $A1 + A2$ and $A1 - A2$, where $A1$ and $A2$ are the respective individual amplitudes. These slow periodic variations in amplitude at frequency Δf are called *primary beats*. Beats are easily heard when Δf is less that 10 Hz, and may be perceived up to about 15 Hz.

Second-order beats: A sensation of beats also occurs when the frequencies of two tones $f1$ and $f2$ are nearly, but not quite, in a simple ratio. If $f2 = 2f1 + x$ (mistuned octave), beats are heard at a frequency x. In general, when $f2 = (n/m)f1 + x$, mx beats occur each second. These are called *second-order beats* or *beats of mistuned consonances* because the relationship $f2 = (n/m)f1$, where n and m are integers, defines consonant musical intervals, such as a perfect fifth (3/2), a perfect fourth (4/3), a major third (5/4), etc.



Binaural beats: An important issue in the study of sound localization concerns the ear's ability to process phase differences at the two ears. One way to study this phenomenon is to present two sinusoids of slightly different frequencies, one to each ear. At low frequencies the sound may appear to fluctuate or beat slowly at a rate equal to the frequency difference between the two tones.

Note that binaural beats are unlike the physical beats that can be heard by a single ear (as discussed above). There, the small difference in the two frequencies causes the physical stimulus to wax and wane in intensity. When the fluctuation is slow enough, the listener will experience a beating sensation. With binaural beats, the interaction between the two tones occurs because of some kind of interaction in the nervous system of the inputs from each ear. The best binaural beats occur at frequency separations of about 30 Hz near 400 Hz and much smaller frequency separations at the higher frequencies. No binaural beats are evident above about 1500 Hz.

Binaural beat example:click here

ITD cues for sound location are derived from the interaural phase. Consequently, tones that are slightly mis-tuned and which are delivered separately to the left and right ear can give the impression of a shifting lateralization from left or right. The example here below shows this. To the left ear we play a 500 Hz pure tone, to the right ear a 500.25 Hz pure tone. So the left and right ear go in and out of phase once every 4 seconds. The left and right ear start in phase, so when listened to over headphones, the sound should start off sounding as if it was in the middle. However, since the frequency in the right ear is ever so slightly higher (the oscillations are ever so slightly faster), over the next 2 seconds the right ear's phase starts to lead by up to 1 ms, giving a changing ITD cue that suggests that the sound is shifted to the right. After more than 2 seconds, the right ear phase leads by more than 1 ms, but since the period of the tones is 2 ms long, the brain may interpret this as a less than 1 ms phase lead in the left ear. So about 2 seconds into the demo, the sound will sound as if it is now suddenly coming from the left, but then it will gradually shift over to the right again over the next 4 seconds, only to then jump again to the left, and so forth. This example can be found at: https:/mustelid.physiol.ox.ac.uk/drupal/?q=node/59

1.5 Localization and Lateralization.

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2 Auditory Demonstrations CD

Tracks from the IPO (Instituut voor Perceptive Onderzoek, Eindhoven, The Netherlands) auditory demonstrations CD can be found at: Auditory Demonstrations TRACKS.

2.1 Demonstration 36: Binaural Beats (track 71)Binaural Beats

1. A 250 Hz tone is presented to the left ear while a 251 Hz tone is presented to the right ear.

2. What did you hear?

2.2 Demonstration 37: Binaural Lateralization (tracks 72, 73, and 74)

1. Listen to tones of 500 Hz and then 2000 Hz with alternating interaural phases of plus and minus 45 degrees.

2. What did you experience with the 500 Hz tone? And with the 2000 Hz tone? What does this indicate about the auditory system's use of interaural time differences?

3. Next, listen to a 100 μs pulse (click) presented with an interaural time difference that cycles from 5 ms to - 5 ms.

4. What did you experience?

5. Finally, listen to tones of 250 Hz and 4000 Hz with varied interaural intensity differences.

6. What did you experience? What does this indicate about the auditory system's use of interaural intensity differences?

3 Binaural Sound Creation

In this lab we make use of a Binaural toolbox for Matlab created by Michael A. Akeroyd. It is highly useful to create stimuli for lateralization experiments.

3.1 Installation

All of the `.m` files in the Toolbox (contained in a single file: all.zip) should be unzipped and copied into a single directory whose name is then added to the MATLAB path (`addpath`). The name of the directory does not matter so something like "**binauraltoolbox**" will suffice. The location of the directory is also immaterial: the only requirement is that it can be accessed by MATLAB.

3.2 Creating binaural stimuli with Matlab

With aid of the Auditory_Toolbox_Tutorial.pdf manual and your knowledge about Matlab from the previous Lab assignment, you should be able to synthesize a dichotic pure tone that is different in level (power) between the two ears.

For example, examine the following code:

```
wave = mcreatetone(500, 40, 50, 0, 0, 250, 20, 50000, 1);
mwaveplay(wave, -1, 'stereo',1)
mwaveplot(wave, 'stereo', -1, -1);
```

What does it do?

Other examples are:

```
%   to make a 500-hz tone, of 60-dB power in each channel,
%   of 500-us ITD, o-degrees IPD, 250-ms duration, 10-ms gates,
%   and 20000-Hz sampling rate, type:

wave1 = mcreatetone(500, 60, 60, 500, 0, 250, 10, 20000, 1);
%   to use an IID of 10 dB instead of a 500-ms ITD, type:
wave1 = mcreatetone(500, 50, 60, 0, 0, 250, 20, 20000, 1);
%   to use an IPD of 90 degrees instead of an ITD or IID, type:
wave1 = mcreatetone(500, 60, 60, 0, 90, 250, 20, 20000, 1);
```

Your task is to recreate the sound tracks 72, 73, 74 of the Demo CD with the auditory toolbox.

3.3 Testing for Minimum Audible Angle (MAA)

Finally, consider how you can setup an experiment to determine the minimum audible angle (MAA) induced by interaural differences in either Level (power) or time of arrival. See for example: http://hearcom.eu/prof/DiagnosingHearingLoss/SelfScreenTests/Localisationtest2_en.html

Provide a Matlab-Script that can perform this test.

Discuss if you would consider this a localization task, or alternatively, a "pure" discrimination task?

Discuss how the absolute distance between the ears could influence the MAA. For other examples of widely separated ears click here.