

Section: Monday / Tuesday
(circle one)

Name: _____
Partners: _____

PHYSICS 107 LAB #11: THE EAR PT. 2: SOUND SOURCE LOCALIZATION

Equipment: computer, headphones, Audacity program, various plug-ins (downloaded from online), partner, protractor, string

OBJECTIVES

Understand the physical cues and psychological effects for aurally locating a sound's source

1. Interaural time difference (ITD)
2. Interaural Level difference (ILD)
3. Anatomical transfer Effect (ATE)

Readings:

Section 15.6, Sound Localization handout – www.aip.org/pt/nov99/locsound.html

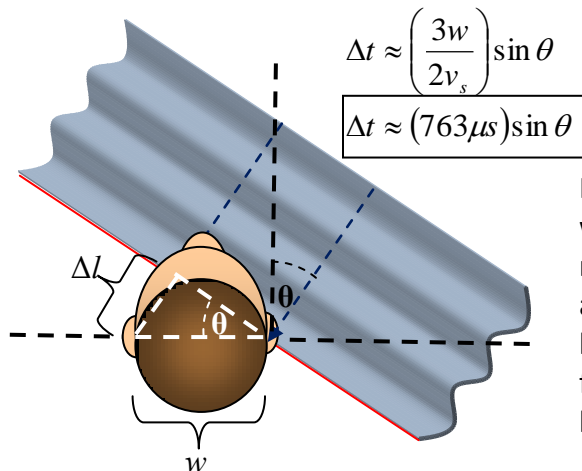
Overview

Close your eyes and just listen for a moment; pay attention to not just *what* you hear, but *where* you hear it coming from. Perhaps you hear a door close behind you, a car go by to your right, a clock tick to your left and above, or a foot tapping just below you. Even with your eyes closed, you have little difficulty determining the locations of the door, car, clock, and foot, just from their sounds, but what is it about these sounds, these traveling undulations in air pressure, that you subconsciously use to locate their sources? In this lab, you'll explore three physical cues that allow you to locate a sound source. First, since sound waves travel at finite speed, there's the slight time lag between when the same part of a sound wave reaches the ear nearest and the ear furthest from the source; this is called the Interaural Time Difference (ITD). Then, just as your head can cast an optical shadow of a light source, it can cast an acoustic shadow of a sound source – making a sound, particularly its high-frequency components, weaker on the left side of your head; this is called the Interaural Level Difference (ILD). Finally, a given source will sound subtly different if it's positioned in front, above, or behind you, thanks to the different degrees of 'shadowing' provided by your outer ears (which point somewhat forward) and the different reflections from your chest, shoulders, and back; we'll call this the Anatomical Transfer Effect (ATE.) While these three cues are too subtle for you to consciously recognize them, the sensitive detectors and signal processors that are your auditory system quite easily interpret these cues for you subconsciously to tell you where that closing door, speeding car, ticking clock, and tapping foot are. As an example of how scientific knowledge leads to technological application, 3-D audio effects in video games and music are based on simulating these three cues. You will use a sound-processing program, Audacity, to control the cues and explore your remarkable ability to detect and interpret them.

Part One: Interaural Time Difference (ITD)

Theory

As illustrated below, sound waves approaching the head obliquely travel roughly $\frac{3}{2}w\sin\theta$ further to reach the far ear than the near ear where w is the head's width (approximately 17.5 cm), and θ is the direction to the source relative to straight ahead. Dividing this distance by the speed of sound, v_s , gives the time lag between when identical parts of the sound wave reach one and then the other ear; this is the Interaural Time Difference (ITD),



In this simple illustration, the sound waves would travel an extra distance $\Delta l = 2a \sin \theta$ to reach the right ear; however, taking into account that the head is oblong, the ears are back from the middle, and the sound must follow a *curved* path across the right cheek, a better approximation is $\Delta l \approx 3a \sin \theta$

So, for a specific source angle, there will be a specific time lag, or turning that around, for a specific time lag, there is a specific source angle,

$$\theta \approx \arcsin \left(\frac{\Delta t}{763\mu s} \right).$$

Thus you subconsciously use this time lag to determine the angle to a sound source.


Experiment

First, you'll get qualitatively familiar with this effect by listening to a sound file that appears to pan back and forth simply because of a slowly changing time lag. Next, you'll get more quantitative and see if you can simulate specific source angles for your lab partner / guinea pig. Finally, you'll explore the limitations of this effect, and thus the need for our minds to use additional cues in locating a sound source.

A. Qualitatively Experiencing ITD

You will apply a slowly oscillating ITD – the sound is delayed at one ear, neither ear, the other ear...

1. On a computer open Audacity from the Start Menu, and through it open Wizard of Oz (short).


2. Next, go to the “Effect” tab and click on “Dual Tape Deck” (below the divide in the drop-down menu). In it, set LFO Frequency to 0.1 Hz, Depth to 0, and Phase Difference to 180°, then hit “ok”.
3. Now, there’s some glitch in the program so it doesn’t seem to ‘take’ the first time you do this, so hit the undo button  and then repeat step 2.
4. Put on the headphones, making sure they’re the right way (“R” at right ear, “L” at left ear.)
5. Play the track.
6. **Question:** What does the sound source seem to be doing?

7. To see the cause of this effect...
 - a. Replay the track and pause when the source sounds to be strongly *left*. Click on the green line that marks the pause location and then zoom in on that region until you can see individual peaks in the wave forms (if you wish to adjust the vertical scale, you can right or left click on the vertical axis).

Question: which track, left ear / top or right ear / bottom, produces a given sound peak first?

- b. Zoom back out and then resume playing the track until the source sounds to be strongly *right*. Again, pause, click on the green pause marker, and then zoom in until you can see individual peaks in the wave forms.

Question: which track, left ear / top or right ear / bottom, produces a given sound peak first?

8. Stop (as opposed to just “pause”) the audio file and undo the effect by clicking the  button.

B. Comparing Intended and Perceived Source Angle

In this section you’ll take turns being the ‘experimenter’ and ‘subject.’ As experimenter, you’ll use ITD to simulate different sound locations and then play your altered sound files for your subjects. As subject, you’ll listen to such sound files and indicate the apparent locations of their sources.

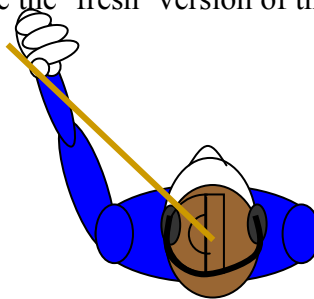
1. Each lab partner should *independently* fill in the first two columns of the table on the next page; two angles are selected for you, select the others to progress counterclockwise from full right to full left (you don’t need to take equal steps, but don’t jump back and forth – people are better at identifying relative than absolute directions) and for all calculate their

associated time differences using the boxed equation on page 2. *Don't let your partners know what angles you've selected.* Positive angles and times are for sources to the listener's right and negative angles and times are for sources to the listener's left.

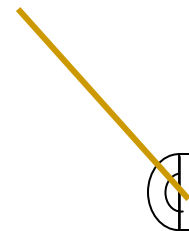
Note: Thanks to the "cone of confusion" effect, the listener will sometimes perceive an acute angle and sometimes perceive the complimentary obtuse angle; always record the acute (<90°) angle

Experimenter's Intended Angle, θ °	Time difference, Δt (μs)	Perceived Angle °	
		Partner 1	Partner 2
90° (full right)	763		
-90° (full left)	-763		

2. One of you initially plays the role of 'experimenter' and the others are the 'listeners' (you'll trade off later.)
3. For each intended angle, progressing either up or down the table (but not jumping back and forth):
 - a. Go to the "Effect" tab and open up "us-ms Time Shifter" (it's below the divide in the drop-down menu.)
 - b. In the pop up box, enter in the calculated time difference from the table above (leave the other two entries "0.")
 - c. Click "Ok" to apply the effect.
 - d. As illustrated below, have the listeners point in the apparent direction of the sound source, then with a protractor and string, you can measure that direction's angle.
 - e. Enter the 'perceived angle' into the table on the previous page.
 - f. **Hit the "undo" button** (looks like a curved arrow pointing left) to remove the time lag and restore the 'fresh' version of the sound file. *This is essential.*



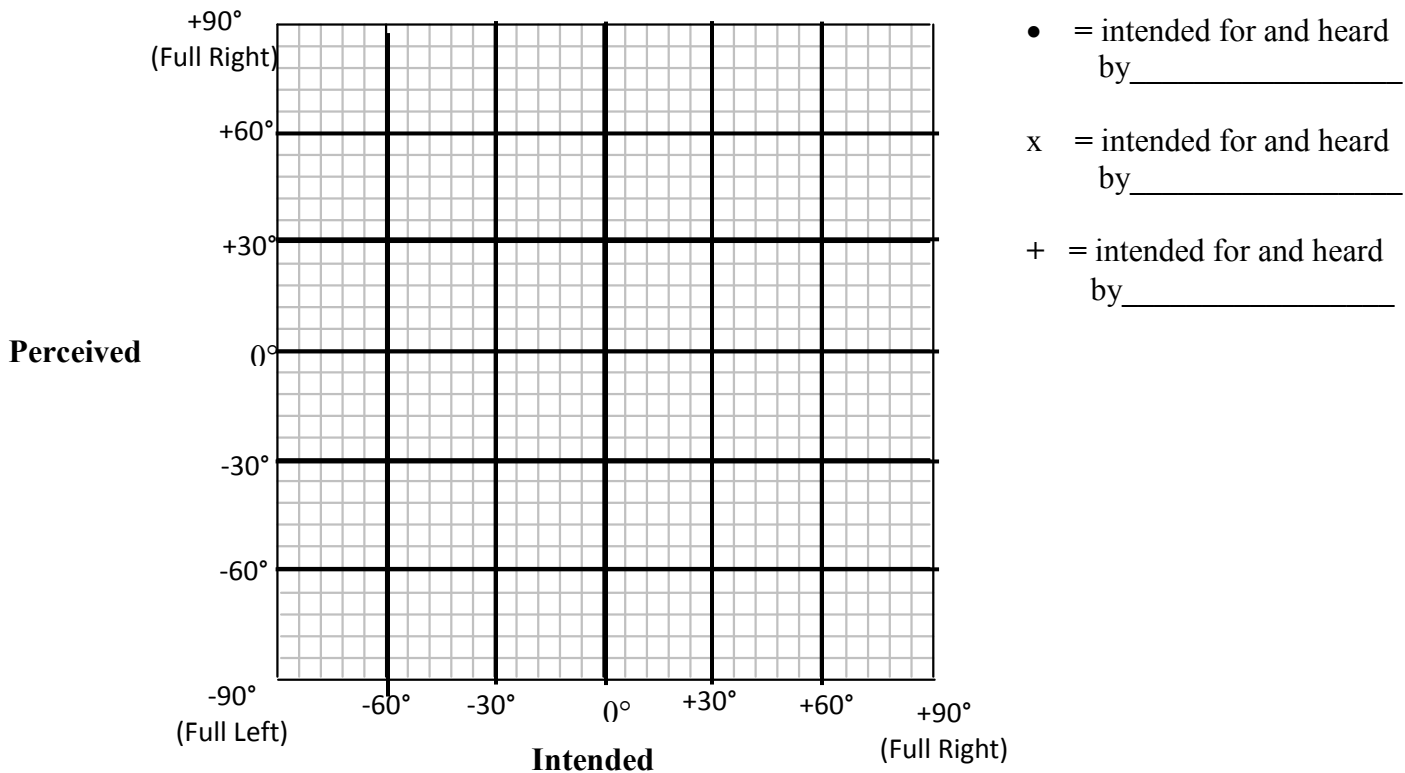
Listener holding up finger in perceived direction.



Respective angle measured by protractor and string

4. Repeat for the next angle.

5. When you've measured the perceived direction for each of your eight time delays, swap roles (listener becomes experimenter and vice versa) and repeat the process so that each partner completes fills in his/her own table.
6. Close the Wizard of Oz sound file by clicking the little x to the left of the waveforms. Do NOT save changes.
7. Plot yours and your partner's results below. So you can distinguish, use different symbols for your data and your partner's data; fill in the key to the right of the plot.



8. To be a little quantitative about how well Intended and Perceived angles agreed, draw a best-fit straight line for the plot above, and measure its slope.

Questions:

1. Is the slope within 10% of a value of 1 (which would be the expected value of the slope)?

2. Is there a particular range of angles that were more difficult to distinguish from one another?
3. How did the data for each of you compare, did some of you have significantly easier or harder times associating directions with the sounds?

Part Two: Interaural Level Difference (ILD)

Theory:

Picture someone sitting in a darkened room with a single desk lamp in front and to her left. The left side of her face (including her left ear) is strongly illuminated while the right side of her face (including her right ear) is shaded. How dramatic the lighting difference is on the two sides of her face depends on how far the lamp is from dead left. Now imagine that the desk lamp is replaced by a speaker. Qualitatively, the same thing happens – the right ear is ‘shaded’ by the head and the sound is less intense there. How dramatic the sound difference is on the two sides of her face depends on how far the lamp is from dead left. This difference in volume, or sound level, is known as the Interaural Level Difference (ILD). It provides another cue for you to subconsciously determine where a sound is coming from. An important difference between the light and sound shading effect is that, thanks to its much longer wavelength, sound more readily bends or diffracts around a head to ‘illuminate’ the far ear. In fact, there’s a significant ILD only for short-wavelength / high-frequency components of a sound, conveniently the range for which ITD fails. So, when a sound is ‘brighter’ at, say the left ear (stronger high-frequency components) than at the right, we determine that the sound is coming from the left.

In the next part of this lab you will adjust an equalizer to gain a similar effect as done in the part above. The equalizer allows you to adjust the volume for different frequency ranges independently (turning up/down the bass, the mid-range, the treble) this will allow you to sculpt the left and right channel sounds differently to simulate the different source locations. In this set up Equalizer 1 will be the left channel and Equalizer 2 will be the right channel.

Question: Given this information, how might you adjust the two channel’s equalizers to make the sound seem to come from the left?

Experiment:

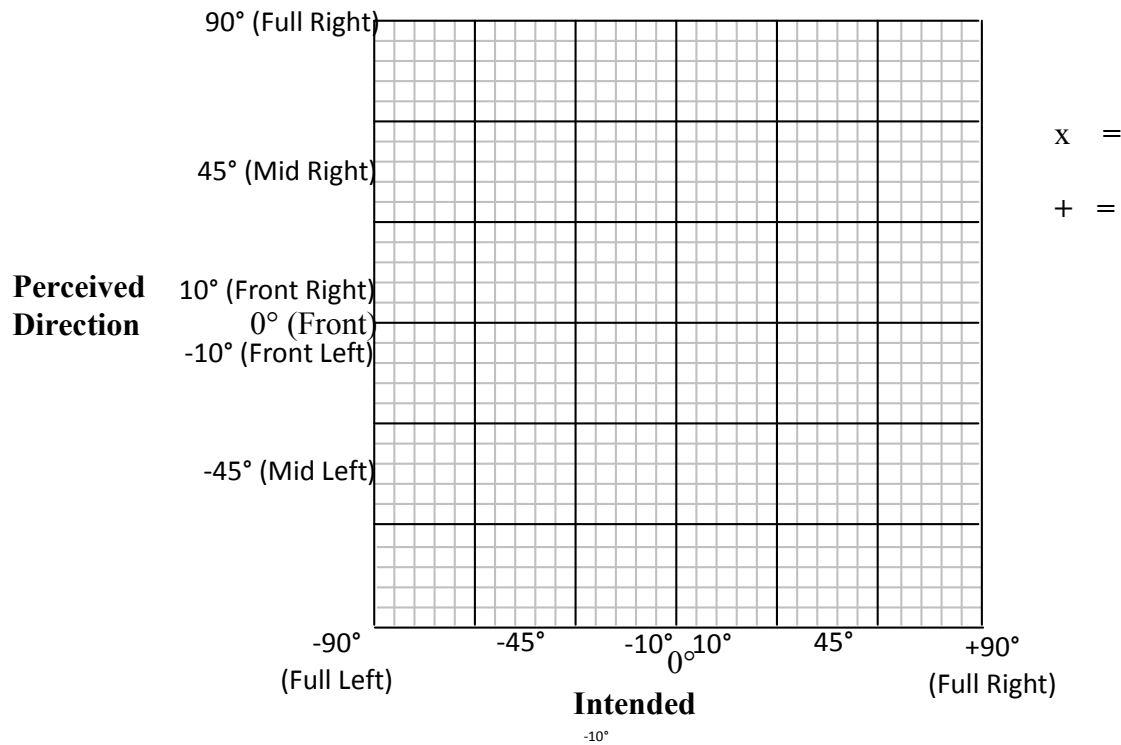
1. In Audacity, reopen the Wizard of Oz (short) audio file.
2. Choose one person to be the ‘experimenter’ and the others to be the listeners. Everyone can put on headphones, but the ‘listeners’ should also face away from the computer.

3. To experience the ILD effect, click on the “Effect” tab and click on “Kjaerhus Audio: GAC 1...” (you’ll have to close a webpage that pops up), then click the “Load” button. In the window that pops up, open the “AutoSave” folder. In this folder there are several saved settings for the equalizer, each designed to make the source sounds like it is coming from a different direction.
4. The experimenter should then choose a setting and click “Open”, click “Ok” on the equalizer to apply it, and then play the audio for the listeners.
5. The listeners should then point the direction of the sound source. And the direction can be measured as before. Enter the “intended direction” and “perceived direction” in the table on the next page.
6. Repeat this process for five more settings and be sure to record the chosen file and the perceived location of the listener in the data table below.

Intended direction	Perceived direction	
	Partner 1	Partner 2

7. If there are just two of you, switch roles and repeat; if there are three of you, don’t switch and repeat unless you want to.

8. Plot yours and your partner's results below. So you can distinguish, use different symbols for your data and your partner's data.

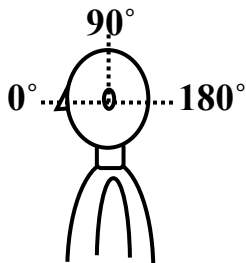


Question: Was the agreement between intended and perceived angles better or worse than it was during the ITD portion of the lab?

Part Three: Anatomical Transfer Effect (ATE)

Theory:

A similar effect can be used to determine how much in front, above, or behind a sound source is, i.e., the angle in the *median plane* (illustrated below.)



In this case, the listener's anatomical build will affect the sound received in the listener's ears. For instance, since that ears are angled slightly forward, sounds from in front will be 'brighter' (have stronger high-frequency components) than sounds from behind, and sounds from above will also reflect from the shoulders back to the ears. (Similarly to the section above, the ATE in this case is mostly affected in the higher frequencies).

Experiment:

1. In Audacity, open up the Wizard of Oz (short) audio file.
2. Click on the "Effect" tab and click on "Equalization..."

3. In the drop-down menu box below the graph, you can select different pre-sets including “Trial One Forward”, “Trial One Above (Good)” and “Trial One Behind (Good)”. The “experimenter should select one and apply it by clicking “Ok”.

4. In the table below, indicate which direction you selected, then play the track and record the direction that the listener(s) perceived. It’s pretty subtle, so for comparison sake, you can stop the track, click the undo button (curvy back arrow) and play the raw track, stop it again, click the redo button (curvy forward arrow) and play the equalized track again.

5. Undo the effect and then repeat the process for the other two directions.

Intended direction	Perceived direction	
	Partner 1	Partner 2

Part Four: All Three Effects at Once

Using what you have learned in this experiment, modify an audio file so that the following locations can be perceived by a listener. Check off with your instructor before going on to the next one. Be sure to start with a fresh audio file each time. (Notice that for the equalizer, there are some pre-saved settings in the drop box at the bottom of the window, use these to get the equalizations correct.)

1. Open the Wizard of Oz (short) file again.

2. Use an ITD and an ILD to get a 90 degree angle to the right, and equalize it to the front of the listener. To do this...
 - a. Use “us-ms time shifter” to apply an ITD for 90° to the right

 - b. On top of that, use the “Kjaerhus Audio: GAC 1...” to apply the pre-saved ILD for “90 full right”

 - c. Finally, use the “Equalization” and from the drop box at the bottom of the window, select “Forward 1” (in front) to produce the ATE for a sound source in front.

3. Listen to the sound file now that all three effects have been applied. To hear each one's effect, you can use "undo" to remove and reapply one, two, or all three effects.
4. Similarly, use an ITD and an ILD to get a 10 degree angle to the left and Equalize it for the ATE of a source above of the listener (Above 1), and listen to the composite effect.
5. Finally, use an ITD and an ILD to get a 45 degree angle to the left and Equalize it for the ATE of a source behind the listener (Behind 1), and listen to the composite effect.

Question: For this last direction, remove and reapply the individual effects, then consider, which would you say produces the most realistic sense of the source's location: No effect, just ITD, ITD + ILD, or ITD + ILD + ATE?

P.S. These three effects naturally color how you hear a real sound source and are simulated (much as you've done in this lab) to give apparent sound source locations in video games. You actually use one more cue to help determine where a sound is coming from – how these three effects *change* when you slightly tip, tilt, and turn your head. Someday, headsets for computer games will have gyroscopes in them (like many smart phones do) to detect head tilts and so tell the game console how to change the ITD, ILD, and ATE appropriately.