

How do listeners
locate sources of
sounds?



**ASSIGN
BUSTER**

How do listeners decide where sources of sound are located?

Abstract

As human beings, we have remarkable abilities to help us function in a world full of different wonders and dangers. One of these incredible functions is audition due to changes in the air pressure that cause our ear drums to vibrate and lead to a chain reaction that results in psychologically perceived sound (Sivonen & Ellermer, 2011, p. 169). We are able to know that there is a guitar playing in a band next door or that a dog is barking across the street through sound localization. Sound localization involves many techniques, including interaural time differences, and interaural level differences, structure of pinnae and sound loudness. Spatial hearing allows us to tell where sounds originate from in space in order to orient ourselves and get by in our world.

Keywords : sound localization, spatial hearing, interaural time differences, interaural level differences, pinnae, loudness

Our sound localization is all too possible thanks to the way our auditory system is structured. We have two ears on our heads; one on the right and one on the left. Much like our eyes, our ears' position on our head can give us vital information about space. Being able to perceive sound from both sides of our head provides us with a binaural auditory system (Plack, 2005, p. 174). This system is able to utilize a couple of different cues to tell where a sound source is coming from.

When it comes to sound, our ears do not usually receive it at the same time. Depending on direction, the sound waves will reach one ear first. According to Plack (2005), the best measure for direction in low frequency sounds is the interaural time difference, the difference in arrival time between the two ears (p. 176). Take for instance a sound directly to your left at 90 degrees azimuth, 'azimuth' meaning the sound is on a horizontal plane in respect to your head (Plack, 2005, p. 174). This sound will arrive at your left ear first, diffract around your head and then reach your right ear. Since the sound reached your left ear first and caused an arrival time difference, we determine the sound came from our left. In a study by Smith and Price (2014) of previously published data by Mills and Schmidt, it was found that the sensitivity of relative sound localization depends on just noticeable differences in ITD and the rate of change of angle with ITD (p. 5). When the just noticeable differences were uniform or near uniform they resulted in poor lateral acuity (Smith and Price, 2014, p. 5). This infers that ITDs are important at sound localization given that they detect small differences in location.

However, according to Plack (2005), with pure tones of higher frequencies, around 750 Hz and above, ITD's become much less informative about the direction of sound (p. 177). This is due to the ITDs being greater than half a cycle of the pure tone, resulting in wave peaks from both ears being really close together (Plack, 2005, p. 177). This makes it seem as if they reached both of the ears at the same time, making it difficult to distinguish from where the sound is coming from. Yet, our auditory system is clever and has another tool to figure out direction of sound: interaural level differences.

Interaural level difference, measured in dB, is a difference in sound pressure level between the right and left ear due to the acoustic shadowing effect of the head and external ears (Binder, Hirokawa, and Windhorst, 2009, p. 1996). Moore (2008) states “ Low-frequency sounds have wavelengths which are long compared with the size of the head, and as a result they bend very well around the head. Thus, little or no ‘ shadow’ is cast by the head” (p. 174). With no ‘ shadow’ there is no ILD, making this a weak measure in determining the direction of sound with low frequencies (Periša, 2004, p. 278). However, higher frequencies have shorter wavelengths compared with the dimensions of the head and do cause a ‘ shadow’ (Moore, 2008). ILDs play a part in figuring out direction in high-frequencies where ITDs fail to. ILDs also help with spatial localization, as seen in many studies, such as the one by Francart, Lenssen, and Wouters (2011) where enhancing the ILD of bimodal listeners showed an improvement of localization performance by 4 – 10 degrees absolute error (p. 2824).

While having two ears does permit listeners to have spatial awareness, there are still problems that arise and cause ambiguity. Take for instance sounds anywhere on the median plane. The median plane is vertical in relation to the head and whether it is straight ahead, behind, or above, it has 0 degrees azimuth as it would be equal distances from the two ears (Plack, 2005, p. 174). This creates a problem known as the ‘ cone of confusion’ (Plack, 2005, p. 184). Because the sound reaches both ear simultaneously, it can be uncertain to tell from which direction the sound came from as there is no ITD. Fortunately, there are a couple of solutions the listener can rely on to help alleviate uncertainties.

Our auditory system is not only an internal structure but also an outer one. When sound reaches our ear it travels through the various paths of the pinna before reaching the ear canal, involving multiple delays because of path length differences (Batteau, 1965, p. 164). These delays depend on the orientation of the sound source. Because of the way our pinnae are structured, different paths of sound waves hit and move in different directions to our ear canals, helping us distinguish from where a sound source came. “ For human listeners, the primary cues for sound localization in the vertical dimension are provided by the direction-dependent acoustical filtering of the pinnae, head, and upper body. The resulting spectral cues complement the interaural time- and level-difference cues that are primary determinants of the apparent location in the horizontal dimension” (Macpherson & Sabin, 2003, p. 76).

Yet, pinnae do not work alone. Head movements work with pinnae to get the best spatial information, as seen in a study by Muller and Bovet (1999). Muller and Bovet asked blindfolded subjects to differentiate where a sound came from with either pinnae and head movements, pinnae with no head movements, head movements with no pinnae, and neither pinnae nor head movements (1999, p. 172). It was found that the subjects that could utilize their pinnae and head movements performed the best, those utilizing pinnae without head movements and the latter performed about the same, and those with neither pinnae nor head movements performed the worst (p. 173). This study supported the idea that pinnae could not work alone for the best spatial localization. “ If a sound source is directly in front, then turning the head to the right will decrease the level in the right ear and cause the

sound to arrive at the left ear before the right ear” (Plack, 2005, p. 184). The same procedure can be used with sounds behind: the head movement will cause the sound to reach the right ear before the left ear. For sounds that are directly above or below these head movements will have no effect, but can also be made less ambiguous with the tilting or nodding of the head (Plack, 2005, p. 184-185). Tilting the head will affect the pattern of travel the sound will make through the pinnae as it reaches the ear canal, but only for short sounds as there has to be enough time to move your head (Plack, p. 185, 2005).

While direction can be complicated enough for the auditory system to figure out, telling distance can create yet another challenge. “ If the source intensity is known, then distance can be judged on the basis of sound intensity at the listener’s ear” (Middlebrooks & Green, p. 148, 1991). In anechoic environments, a sound source’s intensity weakens by 6 dB for each doubling of distance (Middlebrooks & Green, p. 148, 1991). If the sound waves are closer, they place much more pressure on the ear drums, whereas if they are farther they have less pressure. Differences in intensity allow the listener to judge distance (Middlebrooks & Green, p. 148, 1991). Yet, in a study by Zahorik and Wightman (2001) it was shown that loudness does not directly occur as a result of distance cue. Zahorik and Wightman found that subjects were able to solve the problem of loudness judgment for different distance sources, while taking in intensity changes caused by distance and source loudness (p. 81). However, when the same subjects were asked to judge distance, they all underestimated them (p. 81). Zahorik and Wightman argued that if accurate source distance estimation was critical for loudness

constancy, then both distance and intensity cue would be required (p. 79). However, because subjects underestimated distance and were still able to solve loudness constancy, they presumed that loudness constancy may not be related to perceived distance, but may be used to determine another cue, such as reverberant sound energy (Zahorik and Wightman, 2001, p. 82). Zahorik and Wightman (2001) believe that reverberant sound energy was very likely as it remained constant with change source distance in rooms (p. 82). They stated that “ information in spatially constant reverberant energy may form the basis of the observed loudness constancy in rooms” (Zahorik and Wightman, 2001, p. 82).

Our auditory system has many complexities to understand and a vast field dedicated to its study. Dissecting the underlying mechanisms that give us the ability to determine where sound sources may seem like a big portion of our ear’s capabilities. Yet, spatial hearing plays a part of a much larger biological and psychological network in hearing and the human body. With such intricate systems, there are countless ways our body is shaped to face the world we live in.

References

- Batteau, D. (1965). The Role of the Pinna in Human Localization. *Proceedings of the Royal Society of London. Series B, Biological Sciences*, 168 (1011), 158-180. Retrieved December 22, 2014, from doi: 10. 1098/rspb. 1967. 0058
- Binder, M., Hirokawa, N., & Windhorst, U. (2009). Interaural Time Difference. In *Encyclopedia of Neuroscience* (p. 145). doi: 10. 1007/978-3-540-29678-2_2498

Francart, T., Lenssen, A., & Wouters, J. (2011). Enhancement of interaural level differences improves sound localization in bimodal hearing. *The Journal of the Acoustical Society of America*, 130(5), 2817-2826. Retrieved January 8, 2015, from <http://dx.doi.org.ezp.lib.rochester.edu/10.1121/1.3641414>

Macpherson, E., & Sabin, A. (2003). Vertical-plane sound localization with distorted spectral cues. *Hearing Research*, 306, 76-94. Retrieved December 22, 2014, from doi: 10.1016/j.heares.2013.09.007

Middlebrooks, J., & Green, D. M. (1991). Sound Localization By Human Listeners. *Annual Review of Psychology*, 42, 148-149. Retrieved December 23, 2014, from <http://www.annualreviews.org.ezp.lib.rochester.edu/doi/pdf/10.1146/annurev.ps.42.020191.001031>

Moore, B. (2008). 7 Spatial Hearing and Advantages of Binaural Hearing. In (2nd Ed.), *Cochlear Hearing Loss: Physiological, Psychological and Technical Issues*. doi: 10.1002/9780470987889.ch7

Muller, B., & Bovet, P. (1999). Role of Pinnae and Head Movements In Localizing Pure Tones. *Swiss Journal of Psychology*, 58(3), 170-179. Retrieved January 8, 2015, from doi: <http://dx.doi.org/10.1024//1421-0185.58.3.170>

Periša, D., Ivančević, B., & Jambrošić, K. (2004). Sound Localization. *46th International Symposium Electronics in Marine, ELMAR-2004*, 278-282. Retrieved December 19, 2014, from IEEE Xplore Digital Library.

Plack, C. (2005). 9 Spatial Hearing. In *The Sense of Hearing* (pp. 174-186). Mahwah, N. J.: Lawrence Erlbaum Associates.

<https://assignbuster.com/how-do-listeners-locate-sources-of-sounds/>

Sivonen, V. P., & Ellermer, W. (2011). Chapter 7 Binaural Loudness. In M. Florentine, A. N. Popper, R. R. Fay (Eds.), *Loudness* (Vol. 37, pp. 169-197). doi: 10.1007/978-1-4419-6712-1_7

Smith, R., & Price, S. (2014). Modelling of Human Low Frequency Sound Localization Acuity Demonstrates Dominance of Spatial Variation of Interaural Time Difference and Suggests Uniform Just-Noticeable Differences in Interaural Time Difference. *PLoS One*, 9 (2), 1-9. Retrieved January 8, 2015, from doi: 10.1371/journal.pone.0089033

Zahorik, P., & Wightman, F. (2001). Loudness constancy with varying sound source distance. *Nature Neuroscience*, 4 (1), 78-83. Retrieved January 9, 2015, from <http://search.proquest.com.ezp.lib.rochester.edu/docview/250915333?accountid=13567>