Hearing

Instructor Manual

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This module, *Hearing*, covers the processes of how hearing works. Hearing is a complex process that goes through several systems to compute sound waves to meaning. Loudness, pitch, and timbre are the three categories of sound perception. How these elements work together plays an important part in our sense-making of our auditory environment. Sound waves are processed through the three levels of the ear – outer ear, middle ear, and inner ear – before being transformed into neural signals that are sent to the temporal lobe of the brain. The ability to make sense of sounds is complex and not fully understood. When we hear a sound we are able to orient to its location. Most environments are noisy places with sounds coming from voices, music, general background noise, and other places. The sound waves from these objects hit our ears at the same time, yet our brains can separate them out and we can hear and identify distinct sounds, choosing which to focus on.

Learning Objectives

- Relevant APA Learning Objectives (2.0)
    - Describe key concepts, principles, and overarching themes in psychology (1.1)
    - Develop a working knowledge of psychology's content domains (1.2)
    - Use scientific reasoning to interpret psychological phenomena (2.1)
    - Demonstrate psychology information literacy (2.2)
    - Incorporate sociocultural factors in scientific inquiry (2.5)

- Content Specific Learning Objectives: Hearing
    - Describe the basic auditory attributes of sound.
    - Describe the structure and general function of the auditory pathways from the outer ear to the auditory cortex.
    - Discuss ways in which we are able to locate sounds in space.
    - Describe various acoustic cues that contribute to our ability to perceptually segregate simultaneously arriving sounds.

Abstract

Hearing allows us to perceive the world of acoustic vibrations all around us, and provides us with our most important channels of communication. This module reviews the basic mechanisms of hearing, beginning with the anatomy and physiology of the ear and a brief review of the auditory pathways up to the auditory cortex. An outline of the basic perceptual attributes of sound, including loudness, pitch, and timbre, is followed by a review of the principles of tonotopic organization, established in the cochlea. An overview of masking and frequency selectivity is followed by a review of the perception and neural mechanisms underlying spatial hearing. Finally, an overview is provided of auditory scene analysis, which tackles the important question of how the auditory system is able to make sense of the complex mixtures of sounds that are encountered in everyday acoustic environments.

Class Design Recommendations

Hearing can be taught in one class period. Please see the Noba PowerPoint slides that complement this outline.

1st class period (50 min – 75 min):

- Perceptual Attributes of Sound
    - Loudness
    - Pitch

    - Timbre
- An Overview of the Auditory System
- Audibility, Masking, and Frequency Selectivity
- Spatial Hearing
- Auditory Scene Analysis
- Conclusion

Module Outline

Introduction

Hearing is another one of our crucial senses, most of our communication via speech reaches us through our ears. A saying often attributed to Helen Keller, "is that blindness separates us from things, but deafness separates us from people." This module gives an overview of how sound works and is perceived.

Perceptual Attributes of Sound

- There are three main categories for perception of sound; loudness, pitch, and timbre.
- **Loudness:** The loudness of a sound is directly the sound intensity near the eardrum. Loudness is also affected by frequency content, duration, and context.
- There has been a lot of research in refining techniques to measure loudness such as presenting a series of sounds at different levels and rating the perceived loudness or examining how loudness changes as a function of frequency.
- **Pitch**: Pitch variations provide the melody for most types of music and pitch variations in speech provide prosodic information in non-tone languages (e.g., English) and define meaning in tone languages (e.g., Mandarin Chinese).
- Pitch is correlated to waveform repeats. The faster the wave, the higher the pitch.
- Complex pitch sounds contain multiple frequencies and overtones, which are an important part of determining the pitch of a sound. The pitch we here in a harmonic complex is called

the fundamental frequency (F0), and if the F0 is missing, we will still hear that pitch from the complex surrounding sounds.

- Our hearing is limited to a range of pitches, and the musical instruments we play are built within this range.
- **Timbre:** The quality of sound is called timbre. Timbre is what allows us to hear differences in the "same" sound. A violin and a piano playing the same note (pitch) at the same loudness sound different because of timbre.
- When we describe sound as bright, harsh, rich, or dull, we are talking about timbre.

An Overview of the Auditory System

- Our auditory perception depends on how the ear processes sound through its three parts – the outer, middle, and inner ear. The outer ear is the visible part and the ear canal; the middle ear contains the three middle-ear bones and are the smallest in the body; the inner ear includes the cochlea which is what sends neural signals to the brain.
- Sound enters the outer ear through the pinna (the part we see), then the ear canal, and to the tympanic membrane. Our two ears, on opposite sides of our head help us to localize sound as the sound will be different distances from each side.
- The job of the middle ear is to transmit vibrations from the outer ear to the cochlea.
- The inner ear is made up of the cochlea and the temporal bone. The cochlea turns sound vibrations into neural signals to be processed by the brain.
- Hearing is a complex process where auditory signals go through several stages before reaching the primary auditory cortex in the temporal lobe.
- Our understanding of the auditory properties of higher level systems is limited.

Audibility, Masking, and Frequency Selectivity

- The cochlea provide humans with the ability to perceive a wide range of sounds. To quantify this range of sound we use a logarithmic scale called decibles.
- Masking is the process where one sound "masks" another making it difficult to hear. In general a more intense sound will mask a less intense sound. Low frequency sounds are more likely to mask high frequency sounds.
- Most masking is due to how sounds interact in the cochlea, however there are some types of masking that are harder to explain. This less likely form is called informational masking

and can be a failure to separate the target sound from the masking sounds.

Spatial Hearing

- Our two ears give us a 360 degree field of hearing, but even then acuity of specifically locating a sound is not as strong as our visual sense. We can use sound to orient toward a source, then our vision can fill in the exact location.
- There are time differences in hearing – a sound from the left will reach the left ear milliseconds before it reaches the right ear. There are also level differences – a sound from the left will sound slightly higher to the left ear than to the right. These differences allow us to determine a general area from which a sound originates.
- Our perception of distance for sound is largely based on context, such as are we outside hearing a shout or in a cavernous room with lots of echo.

Auditory Scene Analysis

- In most contexts there is more than one sound at a time. All of the different sources of sound in a given place produce sound waves that combine to form a single complex waveform at the eardrum. Somehow the auditory system is able to break down this complex waveform and make sense of individual sounds.
- To explain how this works there are early ideas that originated from the Gestalt psychologists and the ideas proposed for vision.
- More recently computational and neutrally based approaches have been used.
- Understanding how this process really works will aid in new approaches to hearing aids and cochlear implants to provide hearing to the deaf. And also aid in improving speech recognition systems.

Conclusion

- Hearing provides us with an important connection to people around us. We are only beginning to understand the complex processes behind how we make sense of our auditory world.

Difficult Terms

common fundamental frequency
frequency analysis
informational masking
interaural level difference
interaural time difference
timbre
tone and non-tone languages

Lecture Frameworks

Overview

Hearing is another topic that can be difficult for students with many biological terms and systems to learn and remember. Use your goals – and how you will assess this module – to determine how detailed you want to be with explaining each process. If you want students to really understand the biology, focus on the slides and text material. If you want students to have a basic understanding, use supplemental activities to aid in understanding and complete your class period.

First Class Period

- Discussion/warm-up (5-10 minutes)
    - Ask students why they think the senses are important to our understanding of the world. This will be more in depth if you are following a similar discussion with the "Vision" module. Spend a few minutes talking about the importance of all the senses; then guide the discussion to hearing and its importance. Depending on if you have covered language yet, you can bring in the importance of understanding speech for communication.
- Lecture – How Hearing Works: Refer to PowerPoint slides for the following:
    - Introduce three ways we perceive sound: loudness, pitch, and timbre.
    - Discuss how the auditory system works. Your primary goals for this class will determine how much time you spend on these slides. If you want students to fully understand the

complex processes and learn all of the biology, plan to spend quite a bit of time here. If your primary goal is for students to gain a basic understanding of the process, know that this section is a bit confusing and let students know it's ok if they don't remember every part of the ear, and you can spend less time here.

- Activity
- Lecture – Perceiving Sound: Refer to PowerPoint slides for the following:
    - Discuss auditory masking
    - Discuss spatial hearing
    - Discuss auditory scene analysis
- Conclusion
    - Refer to the final slide to discuss where science is today and new research directions.
    - Answer any final questions.
    - You can also use discussion questions from the text here.

Activities & Demonstrations

Haws, L., & Oppy, B. J. (2002). Classroom demonstrations of auditory perception. *Teaching of Psychology, 29* (2) 147-150.

- Localization 1: Use a 30 inch piece of hose with the midpoint marked. Have one volunteer put the ends of the hose to each ear and close eyes. Then tap along the hose and have the student determine if the tap is to the left or right.
- Localization 2: Have two volunteers stand one behind the other. The student in the back gets a clicker. The listener has to determine if clicks come from the left, right, or overhead.
- Frequency and Pitch: Using a 4-foot length of a plugged metal pipe. Slowly fill the pipe with water while tapping and hear the pitch change as the pipe fills.
- Sound Cancellation: Requires a retrofitted stethoscope and a tuning fork.
- Sound Traveling through Different Media: Tie a piece of string to each corner of a wire

hanger (2 strings total). Wrap the string around your index fingers and put your fingers in your ears. Tap the hanger on a table and observe what you hear compared to the rest of the class.

Additional Activities

Supplementary Materials

Limb C. (2011, October). Building the musical muscle. [Video file] Retrieved from **http://www.ted.com/talks/charles_limb_building_the...**

Charles Limb performs cochlear implantation, a surgery that treats hearing loss and can restore the ability to hear speech. But as a musician too, Limb thinks about what the implants lack: They don't let you fully experience music yet. (There's a hair-raising example.) At TEDMED, Limb reviews the state of the art and the way forward. Run time 15:59

Treasure J. (2009, July). The 4 ways sound affects us. [Video file] Retrieved from **http://www.ted.com/talks/julian_treasure_the_4_way...**

Playing sound effects both pleasant and awful, Julian Treasure shows how sound affects us in four significant ways. Listen carefully for a shocking fact about noisy open-plan offices. Run time 5:45

Treasure J. (2012, June). Why architects need to use their ears. [Video file] Retrieved from **http://www.ted.com/talks/julian_treasure_why_archi...**

Because of poor acoustics, students in classrooms miss 50 percent of what their teachers say and patients in hospitals have trouble sleeping because they continually feel stressed. Julian Treasure sounds a call to action for designers to pay attention to the “invisible architecture” of sound. Run time 9:51

Treasure J. (2013, April). 9 ways that sound affects our health, wellbeing and productivity. Retrieved from **http://blog.ted.com/2013/04/24/9-ways-that-sound-a...**

A Ted blog post outlining different ways sounds affect us.

Outside Resources

Audio: Auditory Demonstrations from Richard Warren's lab at the University of Wisconsin, Milwaukee
http://www4.uwm.edu/APL/demonstrations.html

Audio: Auditory Demonstrations. CD published by the Acoustical Society of America (ASA). You can listen to the demonstrations here
http://www.feilding.net/sfuad/musi3012-01/demos/audio/

Web: Demonstrations and illustrations of cochlear mechanics can be found here
http://lab.rockefeller.edu/hudspeth/graphicalSimulations

Web: More demonstrations and illustrations of cochlear mechanics
http://www.neurophys.wisc.edu/animations/

Suggestions from the Society for Teaching's Introductory Psychology Primer

Wells, E. (2013). Sensation & Perception. In S.E. Afful, J. J. Good, J. Keeley, S. Leder, & J. J. Stiegler-Balfour (Eds.). *Introductory Psychology teaching primer: A guide for new teachers of Psych 101.* Retrieved from the Society for the Teaching of Psychology web site: http://teachpsych.org/e-books/intro2013/index.php

POSSIBLE ASSESSMENTS (Out of Class)

One common problem in sensation is the large amount of anatomical structures that must be learned. Students can help study these features by scrolling through interactive sites. These are great for independent knowledge acquisition and to gain familiarity with the anatomical structures. (LO 1.2)

- For the eye: http://www.lensshopper.com/eye-anatomy.asp
- For the ear: http://hyperphysics.phyastr.gsu.edu/hbase/sound/ear.html

Have students compare and contrast any two systems (i.e. vision vs. audition) to further reinforce the process of sensation. This helps students relate to the concept of sensation, perception and how it relates to all of our senses. Assessing sensation and perception when one has suffered an injury or interruption in the process: Randomly assign a case study from "The Minds Eye" by Oliver Sacks. Students should be able to answer questions regarding the sensory or perceptual processes affected. (LO 1.2)

I also like to use an excerpt from the book, "Island of the Colorblind" by Oliver Sachs as a means of getting students to understand the concept of sensation and perception. You could also show them a video of these phenomena available on youtube. This is a 6 part series and will allow you to talk about sensation and perception as well as nature vs. nurture (if that is a theme in your classroom as it is in mine). The video or excerpt could be used in class or as an out of class assessment, possibly as a means to prepare for a potential essay topic.

- http://www.youtube.com/watch?v=CM06G26X-rQ

(In Class)

The brain uses the information it receives to piece together a fairly accurate representation of the external world. One method the brain uses to make meaning from the sensations it receives is through algorithms and past experiences; similar to the way we solve cryptograms. There are a number of websites where students can try their hand at solving these puzzles, such as http://www.cryptograms.org/play.php or http://www.rinkworks.com/brainfood/p/crypts1.shtml Students could either complete the same one or pick their own. Then have the class explain what rules of the English language they used, as well as what past experiences lead to the solution. This allows students to understand that the brain performs a similar task in perception. Students really enjoy this activity and it only takes a few minutes within a lecture. I use it to introduce perception. (LO 1.2)

ACTIVITIES & TECHNIQUES (In Class)

Explain the process of perception using the neural "algorithms" within the brain. (LO 1.2) Gestalt laws of organization:

- These organizational processes can be explained nicely using real examples from art. Students like this way to present perception because they can relate to the art and many have prior knowledge of the pieces I choose.
    - Similarity-Anything from the technique of "Pointillism"
        - Georges Seurat-"Sunday Afternoon on the Island of La Grande Jatte"
    - Proximity-Anything from the technique of Impressionism
        - Monet-"Sunset in Venice". The shadow of the church is a great example of proximity, as well as the refection of the sky in the water.
    - Closure
        - Escher-"Sky and Water", "Ribbon Faces"
    - Figure Ground
        - Anything by Salvador Dali (e.g., "The Image Disappears", "The Slave Market")
    - Good Continuation
        - Anything having camouflage as a theme. Camouflage works because of the principle of good continuation. Usually photography is a great example - http://www.michaelbach.de/ot/fcs_face_in_beans/index.html

Related Background Readings (instructors):

- Verstegan, I. (2005). Arnheim, Gestalt, and Art, New York, NY: Springer Wein New York. http://www.springerlink.com/content/978-3-211-28864- 1/
- Arnheim, R. (1943). Gestalt and art. *The Journal of Aesthetics and Art Criticism, 2*, 71-75.
- Solso, R. L. (2005). *The psychology of art and the evolution of the conscious brain*. Cambridge, MA: MIT Press.

Illusions are a great resource to help explain perception because we are able to see the visual system attempting to correctly solve the puzzle and creating an inconsistent perception. These

are easy to incorporate into a lecture (Most of them taking only a few minutes) and could also be used to assign as an out of class assessment. Michael Bach's website is a treasure trove of visual illusions. This site offers the most current scientific explanations for each illusion. You can select just the right illusion to incorporate into the lecture. What I like about his website is he gives the best explanation for why the illusion exists in a concise and straightforward way. http://www.michaelbach.de/ot/ (LO 1.3)

- Color perception
    - For color perception, using the opponent processing theory, you can use the following image to give students a direct view of the different channels in our brain that code for different colors. There are a number of different images available on the internet. http://gettingstronger.org/wp content/uploads/2010/04/Negative-flag.gif
    - If you are talking about color perception, particularly the retinex theory of color, you can use the Munker illusion. http://www.michaelbach.de/ot/col_Munker/index.html This is a great illusion because it is dynamic and really stresses the point that our color perceptions can change depending on the context of the information received.
- Depth Perception
    - In order to have students understand how the visual system interprets depth, particularly using the binocular cue of retinal disparity, you could incorporate the fun activity of "The Magic Eye" or Stereogram images. These images contain the same information but it is visually offset (i.e. has an inherent retinal disparity) and these different images are then superimposed. Looking at them, students perceive an incoherent image. Only when students force the fusion of the two disparate images does a clear, coherent picture emerge. Therefore, they can see what the brain is able to do naturally. A large index of stereograms are available at this website: http://www.moillusions.com/category/stereograms-optical-illusions
- Auditory illusions are available to help students understand auditory perception. To help students understand how prior knowledge can affect perception use the sound files listed on the following website http://www.lifesci.sussex.ac.uk/home/Chris_Darwin/SWS/
    - Sine-wave speech is a synthesized speech pattern developed by combining a number of different sinusoids. Without prior knowledge, the sounds may be unintelligible. However, when they know what the words are, suddenly they can comprehend the sine-wave speech. First have students try to decipher the sine-wave speech ("SWS" file). Then play the file listed "demonstration" and replay the corresponding SWS file. Now, students

should be able to clearly comprehend the SWS. This is a really quick demonstration, stresses the importance of interpretation in perception, and the students always enjoy it.

- Taste illusions are easily created with food coloring and a food item. I have used orange juice before and it has worked nicely. Orange juice colored differently will have a profound effect on taste. I have students rate the three different drinks (which are really orange juice without any additive color, OJ with orange food coloring to make it darker, and OJ with a little red food coloring) on different characteristics-real orange taste, sweetness, bitterness, etc. Students will typically rate the three drinks differently. After the demo, I have them rate the taste of two glasses of water with orange and red added to show them that the taste of the orange juice was not physically affected by the addition of the food coloring. Instead, their taste was affected by the visual perception of the drinks. This works better if you have a small class. I have used it in a larger class as an opening activity before class begins and it requires about 8-10 minutes.

    - Based on research by Hoegg and Alba (2007): http://www.jstor.org/discover/10.1086/-510222?uid=3739800&uid=2&uid =4&uid=3739256&sid=56205845433).

- Sensory thresholds and sensory adaptation

    - Sensory threshold or Absolute threshold: Finding a gustatory threshold using water and sugar. Have students add 1/8 teaspoon of sugar to a gallon water jug until they reach the point that they can detect the sugar. It will take approximately 1 teaspoon in a gallon of water to be able to tell the difference. **Note:**this is time consuming and I don't often have the chance to incorporate it into my lecture.
    - Sensory adaptation: A number of different classroom activities are listed that can even be adapted depending on the time available in class. **Note:**I never seem to have enough time to get to these activities because sensation and perception always require more time than I typically allocate.

        - Based on O'Drobinak, D. M., & Woods, C. B. (2002). Compelling classroom demonstrations that link visual system anatomy, physiology, and behaviour. *Advances in Physiology Education, 26,* 204-209. http://advan.physiology.org/content/26/3/204.full.

(Out of Class)

Related Student Reading: I assign this outside of class as a way to get students thinking about perception and as a possible essay topic for an exam.

- Griggs, J. (2010). Windows to the mind. *New Scientist*, 34-39. smc.neuralcorrelate.com/files/inpressfiles/newscientist_100918.pdf

Many students are interested in subliminal advertising or subliminal persuasion. You could incorporate a discussion about the difference between the two. To get the ball rolling you could show them a video clip from Derren Brown (http://www.youtube.com/watch?v=f29kF1vZ62o). (LO 3.1, 5.2)

- A good review of subliminal advertising is Broyles, S. (2006). Subliminal advertising and the perpetual popularity of playing to people's paranoia. *Journal of Consumer Affairs, 40,* 392-406.
- Subliminal perception occurs when our behavior is influenced by a stimulus below our threshold. What should be noted to the students is that subliminal perception occurs in highly controlled environments, usually in the lab. **Note:**I will oftentimes use this for an out of classroom assessment/homework assignment to get students to think critically.
    - Reading: Kazin, A. E. (Ed.), *Encyclopedia of psychology, 7,* 497-499. New York: Oxford University Press

RELEVANT TOP ARTICLES (Annotated Bibliography)

- Haws, L. & Oppy, B. J. (2002). Classroom demonstrations of auditory perception. *Teaching of Psychology, 29,* 147-150.
    - When educators include sensation and perception into their introductory psychology course, vision is more oftentimes discussed with little or no coverage of audition. In this article, the authors give four related demonstrations that allow students to experience auditory perception under different situations and can ultimately enhance the topic of perception in general.

- Horner, D. T. (1997). Demonstrations of color perception and the importance of contours. *Teaching of Psychology, 24,* 267-268.

- This article is a great resource for helping students to understand how one theory of color vision is not enough to explain color processing and color perception. Using visual adaptation and afterimages, the article first explains a demonstration that supports the Young-Helmholtz trichromacy theory of color vision. Changing the stimulus slightly will begin to show that the Young-Helmholtz theory cannot explain every color perception we have. In this case, the opponent processing theory may help to better explain the after image experienced. The color theories are difficult to understand but including these demonstrations allows for a more active engagement in the concept of color perception.

PowerPoint Presentation

This module has an associated PowerPoint presentation. Download it at https://nobaproject.com//images/shared/supplement_editions/000/000/286/Hearing.pptx?1416598888.

About Noba

The Diener Education Fund (DEF) is a non-profit organization founded with the mission of re-inventing higher education to serve the changing needs of students and professors. The initial focus of the DEF is on making information, especially of the type found in textbooks, widely available to people of all backgrounds. This mission is embodied in the Noba project.

Noba is an open and free online platform that provides high-quality, flexibly structured textbooks and educational materials. The goals of Noba are three-fold:

- To reduce financial burden on students by providing access to free educational content
- To provide instructors with a platform to customize educational content to better suit their curriculum
- To present material written by a collection of experts and authorities in the field

The Diener Education Fund is co-founded by Drs. Ed and Carol Diener. Ed is the Joseph Smiley Distinguished Professor of Psychology (Emeritus) at the University of Illinois. Carol Diener is the former director of the Mental Health Worker and the Juvenile Justice Programs at the University of Illinois. Both Ed and Carol are award- winning university teachers.

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