**Overview**

CN560 / BE509 covers auditory perception, physiology, and modeling. We will examine how sound is transduced and transmitted through the auditory pathway, following the auditory signal as it is transformed from acoustic energy to neural code, then considering different stages of processing extract different aspects of sound and meaning. Emphasis is on understanding how the computations along the auditory pathway affect basic human abilities.
The course will introduce and use basic mathematical concepts from signal processing, probability, signal detection theory, and psychophysical methods.

Class Meetings
Lectures will be held in room B03 at 677 Beacon Street (the CompNet building) on Mondays and Wednesdays, 8-10 am. Laboratories will be held during regular class hours.

Prerequisites
Students should be aware that strong quantitative and analytic skills are necessary to perform well in this course, even though formal prerequisites are few. Students must have working knowledge of algebra, calculus, probability theory, and Fourier analysis, and be competent in MATLAB (necessary for homework assignments) or have sufficient programming ability to learn MATLAB on their own. Students not meeting these requirements must consult with the instructor prior to enrolling.

Required book:
Also see the associated web site: http://auditoryneuroscience.com/

Course requirements
All students must complete the four labs and three exams. The exams are meant to test your ability to think critically on the basis of what you have learned in class, synthesizing the material (not simply regurgitating facts). In addition to these requirements, there will be brief homework assignments assigned most weeks when there is no lab or quiz. No provision will be made to “make-up” or missed labs, quizzes, or homework without a note from a doctor.

Homework
Short problem sets will be assigned throughout the semester to provide the opportunity to work through quantitative aspects of the material. Homework is generally due at the beginning of the lecture one week after it is assigned, unless otherwise specified. Homework should be turned in by emailing it me at shinn@bu.edu. Please keep a copy of your email as proof that you sent in your assignment. In case an email is misclassified as spam, this copy of your email will serve as proof that you turned in the assignment on time.

Each homework assignment will be assigned a grade ranging from 0 to 10. Homeworks may be handwritten and scanned (as long as your handwriting is legible). No homework will be accepted late. Your email must be time stamped before the start of the class time on the due date (before 2 pm). Solutions will be distributed on the class web site after the due date.

Students may discuss homework problems and assist each other in learning the material. However, the homework turned in must reflect the work of the individual student. In other words, it is acceptable to discuss approaches to problems and help one another with problems; it is not acceptable to confer when writing up solutions. Most assignments include some coding in MATLAB. Use of code from another student is plagiarism and is not acceptable. Any evidence of inappropriate sharing of code will lead to disciplinary action.

Laboratories
Four laboratories are planned, each utilizing a different technique. Laboratories will be conducted across two of the regularly scheduled class meeting times, as noted on the
calendar. All students must attend the corresponding laboratory sessions to get full credit for the laboratory, unless there is a medical or other documented emergency. For each laboratory class period that a student misses, 20 points (on a 100-point scale, or 2 letter grades) will be deducted from their laboratory report grade. Students are encouraged to work together in small groups of no more than four in conducting and writing up laboratories; however, students may always elect to turn in individual lab reports. If you elect to turn in a group lab report, all participants must sign the write-up to confirm that each person participated in the work, contributed to the write-up, and is responsible for the content of the report. All members of a group will receive the same raw grade on a joint laboratory report (however, this raw grade will be reduced for a group member who misses one or both laboratory meetings for that laboratory). Groups can change from laboratory to laboratory, at your discretion.

Exams
Exams will be closed book; however, you may bring up to two pages (front and back) of hand-written notes to each exam. The final exam will be weighted equally with the other two exams, and will emphasize material covered since the previous exam (although it will test some earlier material as well).

Grading scale and policy
Final grades will be determined by a weighted average of the following grades:
45% Exams 1-3 (15% each)
40% Laboratories (10% each)
15% Homework
Grades will be judged on a curve (i.e., relative to performance of other students in the course), with the mean grade roughly equal to an A-/B+.

Policy on incomplete grades
Grades of I (incomplete) will not be given except by prior agreement the instructor. In the even that you are unable to complete the course requirements, you must contact me no later than November 22 to discuss the possibility of taking an incomplete in the course. If I have not received a formal, written request, your final course grade will be based on the work available to me. If an “I” is granted, any work turned in late to complete the course will marked down by one letter grade. Furthermore, since you will have extra time to complete the work, grading will be stricter than with regular assignments.

When requesting an “I” grade, you must clearly indicate (1) your understanding of what work remains to be completed, and (2) a firm timetable for completion of this work. An “I” will be granted only if the timetable is acceptable. In general, the “I” grade will be turned into a final grade by the final date on the accepted timetable, based on all work received up to that date.

Lecture notes and readings
It is the student’s responsibility to download lecture notes from the course web site. The course covers an unusual collection of anatomical, physiological, behavioral, and computational material. Some topics will be addressed in more detail in the lectures than in the textbook. Supplemental readings for the course will be put on the course web site for download. Most students find it critical to be able to take notes on the slides that are provided to remember what is relevant about each topic.
Policy on attendance
Students are expected to attend lectures, labs, and exams. In the case of a medical emergency or other extreme circumstances, it is the students responsibility to contact another student, determine what material / announcements they missed, and take appropriate action to catch up, as necessary. It is not the instructor’s responsibility to provide make-up materials to the student. Note also that missing laboratory meetings will directly affect the corresponding laboratory grade.

Policy on collaboration
As discussed above (see Homework and Laboratories sections, above), all students are expected to turn in assignments that reflect their own work. No collaboration is permitted on exams (see CAS Academic Conduct Code). Any case of suspected academic misconduct will be referred to the dean’s office. Any work deemed by the dean to be plagiarized will be assigned a failing grade.

The web
A blackboard site is being set up through BU’s Information Technology services for BE509 (this is only the second time I have used blackboard, and last year I found it to be A PAIN IN THE REAR END—so I apologize in advance for that 😊).
From the site, you will be able to access the syllabus, assigned readings, and lecture notes. Note that the material on this webpage is intended for class use only.

Weekly Lectures and Readings
For each week, any required readings are listed; any supplemental material (not required) is so marked. All readings will be available for download from the class website.

9/3 Class mechanics; Intro
We will discuss the course structure, assignments, and other mechanics. We will look at the general structure of the auditory system. We will then discuss some physical attributes of sound and define physical metrics. We will end with a brief tour of laboratory facilities that we will be using later in the semester.

9/8 & 9/10 Why things sound the way they do
As we will see in the coming weeks, the inner ear (cochlea) analyzes acoustic inputs by breaking them down into frequency content as a function of time. This is the heart of Fourier analysis. Moreover, to model how an input acoustic signal is altered from its source of origin to its entry into the ear, from the entry of the outer ear into the inner ear, or even from the inner ear to the firing rate of the auditory nerve, one can use linear-system theory.

Schnupp, Nelken, & King: Chapter 1.
HW1: Making signals in Matlab (due 9/15)

9/15 & 9/17 The ear
We discuss how movement of the basilar membrane, the organ of hearing in the inner ear (cochlea) transforms mechanical energy into neural firing patterns. We examine the anatomical and mechanical processes governing the operation of the cochlea. The function of inner and outer hair cells is described along with the crucial idea of the critical band. We discuss the firing patterns of neurons in the auditory nerve, which transduces all acoustic information to the central nervous system. We cover how the auditory nerve firing patterns relates to the movement of the cochlea and how it depends on the sound reaching the ears.

Schnupp, Nelken, & King: Chapter 2.

HW2: Simulating auditory responses (due 9/22)

9/22 & 9/24 Otoacoustic emissions lab
In this first laboratory, you will measure your otoacoustic emissions—energy generated within and reflected out of your cochlea. The lab will be introduced by a lecture on 9/22 presenting the theory of how otoacoustic emissions are generated. On 9/24, we will meet in the 3rd floor CompNet EEG Laboratory to take measurements. You will be provided with your own data and that of a subject who has strong emissions to be analyzed (due 9/29).

9/29 Cochlear Nucleus
Response properties of the cochlear nucleus (an obligatory pathway for all auditory input) will be presented. Functional implications for the diversity of cell types and cell responses will be discussed and analyzed. Neural circuit models of the different cell types (taking into account both anatomical and physiological results) will be presented.


10/1 Exam 1

10/6 & 10/8 Basic psychoacoustics
In order to meaningfully interpret physiological or behavioral data, it is critical to understand the variability that affects these measures. Basic probability theory underlies much of the analysis used to process all forms of auditory neurosciences results. We will discuss the assumptions underlying basic psychophysical methods and perception of simple sound attributes.

Durlach, unpublished lecture notes.


**HW3: Separating sensitivity from bias (due 10/14)**

**10/14 & 10/15 Periodicity and pitch perception**

*This week, we look at the perception of pitch and timbre. We start by discussing periodic signals, then explore pitch perception for signals that are not strictly periodic. Having considered basic perception of pitch, we then look at models of pitch perception, focusing particularly on rate and place codes.*

Schnupp, Nelken, & King: Chapter 3.


**10/20 & 10/22 Hearing speech**

*This week, we’ll discuss the “source-filter” theory of speech acoustics and how basic speech sounds are perceived.*

Schnupp, Nelken, & King: Chapter 4.

**HW4: Vocoding speech (due 10/27)**

**10/27 & 10/29 FFR lab**

*On 10/27, we will meet in the classroom to learn about brainstem EEG measurements. On 10/29, the class will meet in the CompNet EEG Laboratory for the first 20 minutes, where we will watch how a subject is set up for EEG recording. We will then go to the classroom where we will discuss how brainstem responses are analyzed in MATLAB using a sample data set to see how periodic signals are encoded in the brainstem. The same data set will be distributed for you to analyze (due 11/3).*

**11/3 Hearing loss**

*One of the most important research topics in hearing is hearing loss. Hearing loss is a natural consequence of aging, but is also caused by noise exposure. We will discuss the effects of hearing loss and the reasons it is so difficult to find effective treatments for patients with hearing loss.*

11/5 Exam 2

11/10 & 11/12 Neural basis of sound localization
We will discuss the perception of spatial information and the importance of hearing with two ears, covering basic perceptual phenomena in binaural and spatial hearing. We will discuss physiology the Superior Olivary Complex in relation to spatial hearing. We will look at the original “Jeffress model” of binaural interaction and relate this to responses of Medial Superior Olive (MSO) cells.

Schnupp, Nelken, & King: Chapter 5.

HW4: Computing cross-correlation (due 11/17)

11/17 & 11/19 Binaural hearing lab
The second laboratory explores binaural perception by having you run simple psychophysical experiments on yourself (due 11/24).

11/24 Auditory scene analysis
Because we live in a world full of multiple, competing sounds, what we hear is usually contains gaps of time / frequency in which portions of the sound sources present in the environment cannot be heard due to masking by other sources. The process of segregation addresses how we bind information across time and frequency to estimate the content of auditory objects in the environment. Basic rules governing this process of auditory scene analysis are described and demonstrated.

Schnupp, Nelken, & King: Chapter 6.

12/1 Attention
We cannot possibly process everything that we hear. In the visual domain, a lot of work has addressed the specific cortical mechanisms involved in regulating this competition for resources through directing attention to a source of interest. Until recently, vision researchers have conducted most of the work examining how attention affects performance in the auditory domain. Now, as a field, auditory researchers have become interested in how attention affects performance in psychoacoustic tasks and adjusts how neurons respond to stimuli based on what is behaviorally important.


12/3 Cochlear implants
The most neural prosthesis is the cochlear implant. Cochlear implants use microphones to pick up sound, then process the sound and use the resulting signals to directly stimulate the auditory nerve. We will discuss how cochlear implants work and the ways in which sound is transformed by current cochlear implants. Ph.D. candidate Ross Maddox guest lectures.
12/8 & 12/10 Cortical EEG lab
On 12/2, we will learn about cortical EEG signals, and some of the largest stereotypical EEG responses that are elicited by sounds. On 12/4, we will spend the start of the class back in the CompNet EEG Laboratory, where we will demonstrate some cortical phenomenon on a volunteer class member. We will then go to the classroom to discuss how to analyze EEG cortical responses in MATLAB using a sample data set. The same data set will be distributed for you to analyze (due at final exam).

12/15 Exam 3 (final exam) 9-11 am