

HOMEWORK DUE NOVEMBER 15, 2018 by 6PM

1. Snap your finger. From the time your ventromedial 3rd fingertip forcefully strikes your dorsolateral 4th fingertip (the sound source) to the time a detectable electrical signal appears in your primary auditory cortex (A1) is only about 13 thousandths of a second! ($1.3 \times 10^{-2} \text{ s} = 13 \text{ ms}$.) If you are interested in analyzing that rapid an electrical response, you're going to need an instrument with an even smaller time window so you don't miss the signal. The time-window ("sample period") for capturing the responses of auditory-nerve fibers to sound used in Nelson Kiang's world-class Eaton-Peabody Laboratory of Auditory Physiology is around 10 *millionths* of a second ($10 \mu\text{s} = 1 \times 10^{-5} \text{ s}$). The sample period for fMRI is about 2000 ms. For PET it is even worse (more than 40,000 ms). Fortunately, we can also study the working human brain with EEG and MEG, which are capable of temporal resolutions finer than 1 ms.

Music CDs contain time-discrete, digitized distillations of time-continuous, analog signals generated in the real world by living musicians. The time window over which information about tiny changes in air pressure is condensed into a single binary integer is about 0.0227 thousandths of a second ($2.27 \times 10^{-5} \text{ seconds}$). This sampling period is usually expressed in units of Hertz (cycles per second), the reciprocal of the sampling period: 44,100 Hz, or 44.1 kHz. That's the standard "sampling rate" (i.e., sampling frequency) for all the digitized music on Spotify, iTunes, mp3, and CDs. The loss of information during analog-to-digital signal conversion is why a lot of musicophiles – including a considerable number of you! – prefer listening to analog signals generated by vinyl records. (My college friends and I were tired of dealing with the multi-step vinyl cleaning process and annoying interruptions caused by scratches, so we were happy to switch to cassette tapes when they were proliferating everywhere in the early 1980s in symbiosis with the wildly popular Sony Walkman – a small, battery-powered playback device with lightweight stereo headphones. Sound familiar? The iPod, in a sense, is a digital version of the Walkman.)



One of the first ERP experiments to measure brain responses to harmonic expectancy violations was carried out with actively-performing, literate, Boston musicians with more than 10 years of experience by Anirruddh Patel as part of his Harvard doctoral dissertation, around the same time John Iversen and I were there in graduate school. Ani, a guitarist, did his Ph.D. in Biological Anthropology, John, a drummer, in Speech & Hearing Biosciences & Technology, and I in Neurobiology. Ani published his results in 1998 in the *Journal of Cognitive Neuroscience*, the journal Mike "Giraffe" Gazzaniga founded soon after we moved from Cornell to Dartmouth in 1988. Ani clearly demonstrated that the brain – in less than a second – responds differently to unexpected chords than to expected

chords. The expectancies are thought to reflect internalized cognitive representations of regularities in chord transition probabilities imposed by culture-specific combinatorial rules governing melodic and harmonic progression. We are first exposed to these regularities about mid-way through fetal life, when our auditory systems start working, and are repeatedly exposed to them throughout our lives in a variety of social contexts as a member of a culture with music. (All *Homo sapiens*



cultures have music.) For example, in many genres of popular music in the industrialized world over the past two centuries, there is a high probability that a V (“Dominant”) chord at the end of a boundary (e.g., at the end of a musical phrase, verse, or chorus) will transition to a I (“Tonic”) chord at the start of the following boundary – namely, the V-I (“Dominant-to-Tonic”) transition we’ve listened to a few times in “AABA” structure of The Beatles’ *I’ve Got A Feeling*, from the end of segment A₁ to the start of segment A₂, from A₂ to B, and B to A₃. Expected chords are among the seven chords invoked by the harmonic context (“Key”) established by preceding chords – e.g., the Key *D-Major* in the title of Bach’s *Brandenburg Concerto #5*, *C-Minor* in the title of Beethoven’s *Fifth Symphony*.

Ani succeeded in demonstrating that Key violations in chord progressions evoked an ERP similar to one evoked by Syntax violations in word progressions (i.e., sentences), but the tardiness of the ERP response peak raised doubts about its relevance to real-time music perception. The unexpected chords evoked a positive change in voltage with a peak amplitude around 600 ms after the start of the chord. That’s slow – 1 beat at a tempo of 120 beats per minute corresponds to 500 ms per beat. Meter = 4/4 (four quarter notes = 4 beats per measure); Tempo = 120 beats per 60 seconds = 2 beats per second = 2 beats per 1000 ms = 1 beat per 500 ms.] Many of the chords used in the experiment were less than 600 ms in duration, some way less, so by the time the ERP peaked the next chord had already sounded. Intuitively, based on everyday experience and introspection, one might rationalize that harmony percepts form faster than 600 ms. But introspection doesn’t count – empirical evidence is required. Within a couple of years, an earlier ERP with a more plausible latency was elicited in non-musicians when a violinist–*cum*–neuroscience graduate student, Stefan Koelsch, and his professor, Angela Friederici, an expert in language ERPs, devised a different ERP paradigm at the Max Planck Institute for Cognitive Neuroscience in Leipzig, Germany.

The Harmony Study Group presented Koelsch and colleagues’ ERP experiment that was published in the *Journal of Cognitive Neuroscience* two years after Ani’s ERP paper. A Bach fan, Stefan earned his Masters in Vocal and Instrumental Arts with a Major in Violin then went on to do a Ph.D. in Psychology. Since that 2000 paper, Stefan has published over a half-dozen ERP experiments probing neural correlates of expectancy violations in the Music Domain. His *Nature Neuroscience*

publication with Maess and colleagues that reports music-ERP studies using MEG is also in the Week 4 link on CCLE. The stimuli Stefan composed for the experiment are shown in music notation in Figure 1 of the *JCogN* paper Nikoo and Cindy presented. Without having to read music notation or know what a Neapolitan Chord is – you already heard what an unexpected chord sounds like in the sequences Namir and I played on guitar – just focus your attention on Rows *a* and *c*. Row *a* shows what is called a “Key-Congruent Phrase Closure.” Row *c* shows a “Key-Incongruent Phrase Closure.” (Recall our famous Marta Kutas sentence with a Semantic-Incongruent Phrase Closure, “I like my coffee with cream and *dog*.”) Each harmonic progression is made up of 5 chords. Phrase closure, by definition, occurs at the final chord. So let’s compare the ERPs evoked by Key-Congruent vs. Key-Incongruent Phrase Closures. This comparison is shown in Figure 3a: the dotted line is the average voltage waveform evoked by the last chord of Key-Congruent Phrase Closures (in Leonard Meyer’s Gestalt terminology, the last chord obeys “The Law of Good Closure”); the solid line is the average voltage waveform evoked by the last chord of Key-Incongruent Phrase Closures.

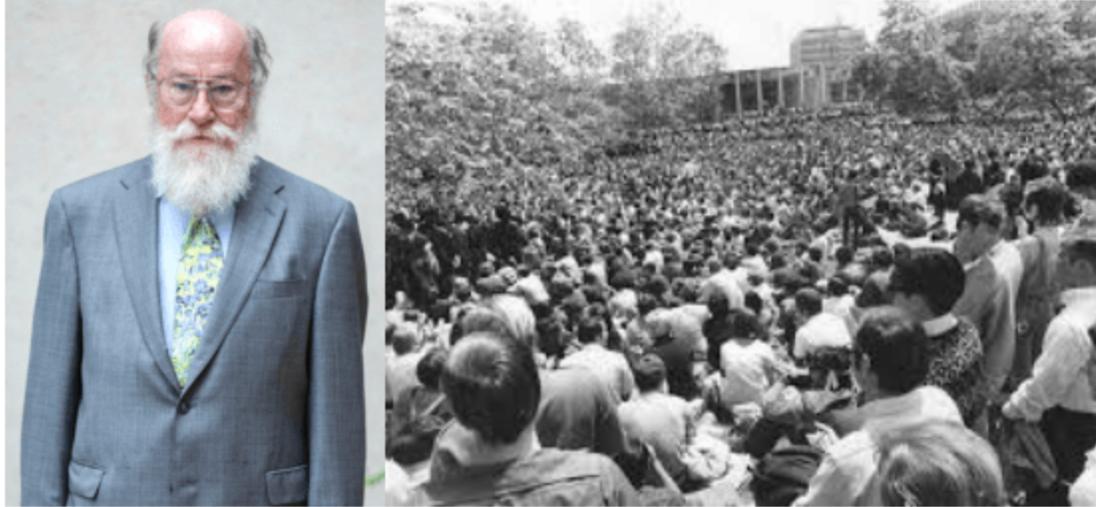
If the proposition is True, put a “T” on the line next to it; if False, put an “F.”

- T Figure 1 of Koelsch et al. (2000) shows that Key-Congruent Phrase Closures (averaged across Closures and Subjects) – evoked a positive wave that peaked a little later than 200 ms (0.2 s; the first tick on the x axis) at all electrode locations.
[Note: the convention in EEGs, ERPs, and Evoked Potentials (EPs) is to call voltage waves above the x axis “negative” and those below the x axis “positive”.] (2 points)
- T Key-Incongruent Phrase Closures (averaged across Closures and Subjects) evoked a negative wave that peaked a little before 200 ms (~180 ms) at all electrode locations (2 points)
- F The negative peak around 180 ms is smaller at electrode F8 (right anterior frontal electrode) than the negative peak at electrode F7 (left anterior frontal electrode) (2 points)
- T The negative peak around 180 ms is bigger at electrode FT8 (right frontotemporal electrode) than the negative peak at electrode FT7 (left anterior frontal electrode) (2 points)
- F Stefan’s ERP results suggest that the brains of non-musicians show no evidence of sensitivity to Key violations at phrase closures.

(4 points)

___F___ Neurons in the right frontal and temporal lobes are *necessary* for harmony perception. (2 points)

2. After getting a Ph.D. in Social Psychology at Harvard and doing a post-doctoral fellowship at the National Institute for Mental Health, W. Jay Dowling came to UCLA an Assistant Professor in Psychology here at UCLA in 1966, the year



th of 'The Beatles' last concert tour. Daron and Lucy presented his first experiment on melody perception with a couple of dozen UCLA undergraduates, who apparently took some time out from protesting the Vietnam War (above, right). Prof. Dowling has been at the University of Texas at Dallas since the mid-1970s, when he did the experiments Waruguru and Jean-Emmanuel are presenting.

Of the many Selected Readings with original experiments I post on CCLE during the Quarter, I would say Dowling's 1978 *Psychological Bulletin* paper is the most relevant to our everyday enjoyment of popular contemporary and classical music – not only because of its original experiments, which we cover in class, but also because of its literature review, which we don't cover in class. All of us can relate to the bits about the NBC chimes, *Twinkle Twinkle*, and *Yankee Doodle*. I think all of you would enjoy reading this paper in full given your interests. It's long but well-written and, hopefully, sufficiently enlightening to be worth the time invested.

Figure 1 in Dowling's *Psychological Bulletin* paper shows six melody excerpts from Beethoven's Piano Sonata opus 14 no. 1 and one excerpt from a Native American song. Underneath the musical staves and notes, there are **numerals** with a “+” or “—” in front of them.

From the list A-D, put the letter of the Figure 1 symbol on the line next to the sentence describing what that symbol means:

- A. “+” or “—”
- B. numerals
- C. both A&B
- D. neither A nor B

B The number of steps (n) the note goes up or down on the Chromatic Scale (i.e., the F0 of the note increases or decreases by a factor of $2^{n/12}$). (2 points)

A The direction of the pitch change from one note to the next. (2 points)

D The number of steps up or down on the Diatonic Scale of the parent Key. (2 points)

3. Figure 3a shows the stimuli Dowling (1978) used in his two-interval, two-alternative forced-choice task and method of constant stimuli. (Sometimes the stimulus in the first interval is called the “standard stimulus” and the stimulus in the second interval is called the “comparison stimulus” because you are comparing the second stimulus with the first stimulus.) UT undergrads’ response choices were “same” and “different.” In real-life, whether one can determine with reasonable certainty if two melodies are the same or different pertains to copyright infringement and plagiarism in songwriting, like when songwriter Ronnie Mack’s publishing company successfully sued George Harrison for plagiarizing Mack’s 1963 hit single, *He’s So Fine* by The Chiffons (https://www.youtube.com/results?search_query=he%27s+so+fine) after George’s *My Sweet Lord* hit #1 on the Billboard Charts for four weeks in 1970-1 (<https://www.youtube.com/watch?v=M1NdcM8tLmc>; https://www.youtube.com/results?search_query=my+sweet+lord+he%27s+so+fine). Take a listen: What do *you* think? George, in his own defense, pointed out that despite being The Beatles’ lead guitarist, sometimes singer, and the composer of a few of their hits (including *Something*, the 1969 composition Frank Sinatra introduced many times as the greatest love song of the 20th century before he sang it at his concerts), he couldn’t read or write music. Moreover, George confessed that *My Sweet Lord* was inspired by the Edwin Hawkins Singers’ 1967 *Oh Happy Day* (<https://www.youtube.com/watch?v=ihGHltBuBBI>). (I don’t think Hawkins ever sued Harrison or that Mack ever sued Hawkins! But George later wrote and recorded *Sue Me, Sue You Blues*, though that song was about the lawsuit needed to break up The Beatles.)

If you want to perform a psychology experiment in order to see how well a listener can discriminate whether two melodies are the same and different, the trials with different stimuli are pivotal: that’s where you get to systematically vary and

contrast stimulus features, such as: 1) the direction of sequential pitch changes that form a melody's contour; and 2) the size of those changes in relation to the listener's mental representation of the pitch hierarchies that are characteristic of a culture's Scales and Keys in one or more genres. (For our math students, mathematical psychologist Roger Shepard modeled the mental representation of pitch height and pitch hierarchies in the form of a double-helix wrapped around a helical cylinder in five dimensions

<https://books.google.com/books?id=YW1aBQAAQBAJ&pg=PA364&lpg=PA364&dq=helix+wrapped+around+a+helical+cylinder,+in+five+dimensions&source=bl&ots=5oEI5XOyUS&sig=8huL7TMba0cGvMHHhNRKPvG5miE&hl=en&sa=X&ved=2ahUKEwjcntmD2sreAhUEU98KHTfXAtoQ6AEwEXoECAUQAQ#v=onepage&q=helix%20wrapped%20around%20a%20helical%20cylinder%20in%20five%20dimensions&f=false>). So to understand the Dowling experiment, one needs to understand how stimulus features are varied on “different” trials.

Are the following propositions about the stimuli shown in Figure 3a True or False? Put a “T” or “F” on the line next to each proposition:

 T The way the “target” melody differs from the standard melody by the *absolute F0s* of each note in the melody. However, because our effortless capacity for auditory computation confers perceptual equivalence in multiplicative transformation (known in Music as equivalence in transposition), the *pattern of relative F0 changes* is the same (on a logarithmic scale). That is to say, the melody has been transposed to a different Key, but it's still the same melody. This is the auditory computation we use to recognize *Happy Birthday* regardless of the absolute F0 of the pitch our singing friends and family start on. (2 points)

 T The “tonal answer” melody differs from the standard melody by the size of one step between two notes in the parent Key (pitch distance), but the directions of the note changes (i.e., the melodic contour) remain constant. (2 points)

 T The “atonal contour” melody differs from the standard melody on “different” trials by both the size of one step between two notes *and* the fact that the deviant note is not a member of the parent Scale of the other notes in the melody. (2 points)

 T The “random” melody differs from the standard melody with respect to contour and/or step size and/or scale membership. (2 points)

4. The results of the 1978 Dowling experiment that employed the above stimulus classes are shown in Table 1. The numbers refer not to percent correct but to the

ratio of “hits” (true positives) to “false alarms” (false positives) – i.e., the “Memory Operating Characteristic.” The MOC (usually called the “Receiver Operating Characteristic”) subsumes an “error analysis” that takes into account any bias the subject might show for “same” or “different” responses.

Type the letter of the stimulus category next to the proposition it matches:

- A. Target vs. Tonal Answer
- B. Target vs. Atonal Contour
- C. Target vs. Random
- D. None of the above

__C__ Whether or not UT undergraduates had ≥ 2 yrs of music training (as defined in the Methods), they did well on the discrimination task that used these two stimulus types. (2 points)

__B__ Students with ≥ 2 yrs of music training discriminated these two stimulus types better than students with < 2 yrs of training. (2 points)

__D__ Students who had ≥ 10 yrs of music training discriminated these two stimulus types better than students with 2-9 years of training. (2 points)

__A__ Both experienced and inexperienced students found it hard to discriminate these two stimulus types, and there was no significant difference between students with ≥ 2 yrs vs. < 2 yrs of musical training.

END