Introduction to Biological Signal Processing

UCLA Psychology 206B – Gregory A. Miller – Fall 2016

Overview

This course is an introduction to common aspects of signal processing used in animal and human neuroscience. Rather than emphasizing specific physiological measurements (fMRI, EEG, heart rate, etc.) and applications (e.g., memory, face perception, health psychology, emotion, language, human factors, psychopathology), this course emphasizes (a) general concepts in basic electronics and signal processing that apply across measurements and (b) how to think about biological phenomena in order to help understand phenomena we commonly think of as psychological. We touch briefly on electromagnetic and hemodynamic measures to study psychological phenomena, applying the general principles we learned in the bulk of the course.

The course is designed for advanced undergrad and graduate students in a variety of disciplines. Our material is relevant beyond psychology and neuroscience, including philosophy of science, biology, medicine, statistics, and electrical and mechanical engineering. What we cover will alter your understanding of biomedical advances as presented (and misrepresented) in popular-media news reports – as well as your understanding of how portable music players work.

Course Description and Objectives

The course will focus on methods used in a variety of branches of neuroscience, with examples drawn primarily from psychophysiology, typically characterized as: studying relationships between psychological and physiological phenomena, using non-invasive measures and human subjects, and using psychological phenomena typically as independent variables and physiological phenomena as dependent variables.

Psychophysiology subsumes nearly all work falling under the labels “cognitive neuroscience”, “affective neuroscience”, “clinical neuroscience”, and “social neuroscience”. Those literatures emphasize brain mechanisms. Psychophysiology includes those but is broader in the physiological mechanisms it considers, such as facial musculature and cardiovascular phenomena responsive to psychological variables. Endocrine measures are also sometimes used.

Much research in all of these areas of neuroscience relies on analog electronics, digital computers, analog and digital signal processing, statistics, physiology, and neuroanatomy as

well as on psychology. We will cover a bit of all of those. The objective of the course is providing considerable familiarity, both conceptual and mathematical, with a variety of concepts and approaches in electronics and signal processing that are used in laboratory neuroscience (and well beyond).

This course is designed to be accessible to advanced undergraduates and graduate students. Permission of instructor is required for undergraduate enrollment. This is a lecture course, with questions and discussion in class strongly encouraged. This is not a laboratory course, providing hands-on experience.

Most of the course will emphasize basic analog electronics and analog and digital signal processing, with brief coverage of relevant basic neuroscience. Along the way we will touch on electrodermal and cardiovascular systems and direct brain recordings as areas of application of what we are learning.

Nothing we cover will require background in physics, physiology, or math beyond high school (no calculus required). Concurrent registration in basic statistics, such as Psychology 100A, will suffice for undergraduates with a good math background. Graduate students have the pleasure of extra required reading, some of which assumes more math background but not beyond what is typically assumed or provided early in relevant PhD programs such as Psychology 250A. Coursework in basic physiology or neuroscience is helpful, but you can pick up what you need along the way within our course. Overall, required reading load is light, with optional readings to suit your needs and interests.

Based on students' experiences in this course in past years, most of you will find the electronics and signal processing stuff more accessible and more interesting than you expect. What you will learn about them will be applicable to many areas in daily life. This background, which you will very likely not have encountered in other psychology or neuroscience courses, is important for understanding many biological phenomena as well as some of the equipment used to record biological signals (and to get through your day, if you listen to music, use a phone, etc.).

Unsolicited testimony from a woman who took the course: “I really enjoyed your class and was surprised by how much I really knew at the end of the course! The material seems very intimidating at first, but you really walk us through all of it, and it's all really practical! I even got to bring up tweeters and woofers today when my brother asked what a 5.1 surround sound speaker system was - I felt very smart.” That is my goal for you…

Lectures, Assignments, Attendance, and Prerequisites

The course schedule below is approximate – how fast we get through each topic varies with

every student cohort. The lectures are not a subset of the readings, nor vice versa. Often the assigned readings will not track the lectures closely but will provide important background or material we do not have time for in lecture. (Some of the positioning of the readings reflects an attempt to even out the workload across weeks.) I will rely more on the readings for some material (e.g., basic neuroscience) and more on the lectures for other material (e.g., electronics, signal processing). In general you will get much more out of the lectures by completing the reading in advance.

Please do the worksheets. They help you and me gauge whether you are on top of the early material, which is important in what follows. Worksheets are due at the start of class and will lose points if turned in late (including later during that class; the payoff in sticking to such rules is your knowing what is expected and counting on being treated fairly).

I will make the readings and my PowerPoint files and handouts available via CCLE (https://ccle.ucla.edu/course/view/16F-PSYCH206B-1), but they do not capture everything the lectures convey. Missing the lectures will be problematic, as there is no way to fully make up for missed material. It is your responsibility to find out what you missed and get the notes from one of your classmates. I will be happy to meet to discuss material our class covers but not to reteach a lecture. I will be updating the PowerPoints as we go, depending on how far we get in each lecture, so they will not be posted much in advance and may be revised after initial posting. I will count on you to check your email.

Arriving to lecture late is a serious sin, disruptive of and disrespectful to the class. You are welcome to use electronic devices in class to take notes. I trust that all other electronics will be suitably neutralized. Please do not record the lectures.

I am happy to share my PowerPoint and handouts with people enrolled in the class. I ask that you not circulate them beyond the class without my permission and not sell your lecture notes.

Readings

The present file is a near-final draft of the syllabus for fall 2016. I may make a few adjustments as the quarter unfolds. There is no single textbook and none required for purchase. I will provide the readings electronically. Keeping up with the readings will be important, even though some readings assigned for a particular lecture are not directly relevant to the lecture. Because I try to even out the reading load, some readings are assigned early, before they are needed for lecture, and it is best not to get behind.

A general reference in the field is:

Cacioppo, J.T., Tassinary, L.G., & Berntson, G.G. (2007) (Eds.), *Handbook of*

psychophysiology (third edition). New York: Cambridge University Press.

We will read several chapters from it. It's (still) a wonderful resource, but at $175 when introduced in 2007 and $239 on Amazon now, I cannot justify requiring you to purchase it. A new edition will appear soon. (I have two chapters in the 2007 edition and one in the new edition, but I don't get a dime from sales of anything assigned for this course.)

You could also consider buying these books, the first two available in paperback, but we will not use most of any of them:

Hugdahl (1995). *Psychophysiology: The mind-body perspective*. Cambridge, MA: Harvard University Press.

Luck, S.J. (2014). *An introduction to the event-related potential technique*. Cambridge, MA: MIT Press. (The 2005 edition is still useful.)

Luck, S.J., & Kappenman, E.S. (Eds.) (2012). *The Oxford handbook of event-related potential components.* New York: Oxford.

Poldrack, R.A., Mumford, J.A., & Nichols, T.E. (2011). *Handbook of functional MRI data analysis.* New York: Cambridge University Press.

If you get carried away by one of our topics, digital filtering, I'd recommend Edgar, J.C., & Miller, G.A. (2016). *Digital signal processing.* Mathable, Inc., Champaign, IL. It's an e-book in an online Mathematica environment.

Scattered throughout the readings are papers on statistics. They apply generally, not just to the other readings in a given week. Undergraduates should feel free to read any of the graduate-only assignments. All are invited to read all the pages in readings where just a subset are required.

Optional readings: Some provide a more basic introduction to unfamiliar material if needed, some provide additional background (e.g., substantive material in neuroscience), and some provide additional sampling of diverse research methods and applications. You can pick what you find interesting. You will not need to do the optional readings for the exam.

Grading

There are 4 graded take-home worksheets about electronics and signal processing and 1 exam. There are no term papers or student presentations. The exam will be cover the whole quarter.

40% 10% for each of four electronics worksheets: full credit if you turn in a good-faith effort on time, including no blank entries; partial credit if late or incomplete; later means less credit; the last 2 worksheets are longer than the first 2 but have

a lot of overlapping material and will go quickly if you know the material

30% class participation (asking questions after and especially during class counts!)

30% exam

Grading will not be strictly on a curve, though I will look at the undergrad (if any) and grad histograms separately. Exams will be a mixture of multiple-choice questions, other "objective" questions, and fill-in-the-blank or short-essay questions. Be prepared to draw or analyze simple circuits of the sort emphasized in lecture and on the worksheets. Exams will rely on both lectures and readings. Anything covered any time in the course will be fair game on the final, unless I announce otherwise.

Miscellany

Feel free to contact me outside of class about any aspect of the course. I appreciate feedback and suggestions any time. Most students do not talk with their instructors nearly as often as they should. Do not hesitate to email me, to make an appointment to meet with me, or talk to me after class.

Lectures: Mondays 12:10-2:50pm (including a short break); there is no lab, no TA

Email: gamiller@ucla.edu (email is the best way to contact me – do not rely on phone messages – I do not use voice mail, I almost never text, I consider social media too insecure, and I may not get a written phone message quickly; note that if you email from a non-UCLA address, such as gmail, I do not know whether it is really you)

Office & phone: Franz Hall 1257D, 310-825-2288; and 3277, 310-206-3252

Office hours: by appointment

Standard policies: UCLA has policies about illness, academic integrity, cheating, etc. Needless to say, you are responsible for following them. So am I.

Tentative Lecture & Reading Schedule

1) Monday 9/26 Perspectives on Biological Signal Processing;
Start on Basic Electronics and Analog Filters

Electronics Worksheet #1 distributed in class (due @ start of class 10/10)

Shown in class: https://www.youtube.com/watch?v=7_AiV12XBbI =
AmazingPendulumWaveEffect_YouTube_144p_051216.flv and
http://en.wikipedia.org/wiki/Image:ECG_principle_slow.gif

2) Monday 10/3 The Scope of Biological Signal Processing;
Electronics, Filters, and Signal Processing

Handout 1 = H1.pdf

Miller, G.A. (2000). Editorial. *Psychophysiology, 37*, 1-4. [MillerEditorial2000.pdf]

Fabiani, M. (2015). Editorial. *Psychophysiology, 52*, 1-5. [FabianiEditorial2015.pdf]

Hugdahl (1995), Chapter 2, pp. 32-46: Concepts and terms. [Hugdahl1995ch2.pdf]

Miller, G.A. (2013). *RC filters*. Unpublished manuscript. [RCfiltr_020313.pdf]

Beaty, W. (1996). Which way does the "electricity" really flow? From amasci.com/amateur/elecdir.html accessed 07/23/07 [Beaty1996.doc]

Morrison, R. (2003). *Electricity: A self-teaching guide.* Hoboken, NJ: Wiley. Pp. 19-35, 39-61, 121-125, 137-142, 154-157, 176-178. [Morrison2003.pdf – do not confuse this with Morrison2004.pdf, assigned for next week]

Optional:

A more basic introduction than Cacioppo et al. is Hugdahl (1995), Chapter 1, pp. 3-31: An overview of psychophysiology. [Hugdahl1995ch1.pdf] If you find the Cacioppo et al. chapter heavy going, start with Hugdahl. But the Cacioppo et al. chapter is still then worth tackling.

Cacioppo, J.T., Tassinary, L.G., & Berntson, G.G. (2007). Psychophysiological science: Interdisciplinary approaches to classic questions about the mind. In Cacioppo et al. book (pp. 1-16). [CacioppoTassinaryBerntson_Chapter1_2007.pdf]

Increasingly, materials are available on the Web that you may find helpful. A series of YouTube videos on signal processing by Prof. Barry Van Veen at Wisconsin is better than others I have checked out. The pace is often too slow, then suddenly much more formally algebraic than I will teach it, but it is explained well and may be helpful. Here are two short segments I can recommend, a starting place if you want to poke around on the Web. If you find good sites, please point me to them, and I may share them with the class.

1) http://www.youtube.com/watch?v=YmSvQe2FDKs&list=PLGI7M8vwfrFPtrWL_o6CluZYkshj-hqUr

Just 2:50 to 10:00 is worth watching. Do not sweat any mention of the Doppler effect or any equations mentioned (especially if you go past 10:00).

2) http://www.youtube.com/watch?v=fCAZ7jcO-vc&list=PLGI7M8vwfrFPtrWL_o6CluZYkshj-hqUr

This one relies on basic trigonometry starting at 2:00, more than you will need for our class. If you are not rusty on your trig, it is a good intro. Otherwise, stop at 2:50. We will cover all you need in class, more accessibly.

3) Monday 10/10 Electronics, Filters, and Signal Processing; A Bit of the Big Picture – the Nature of Data

>> Electronics Worksheet #1 due at start of class <<

Start on Electronics Worksheet #2 (due @ start of class 10/17)

Watch in class: AllenCommandingTheLake.MPG/.THM (not uploaded) to illustrate sinusoidal phenomena and some sampling issues

- What sinusoidal examples do you see?
- What if you had a wave detector every meter along the beach? how redundant would they be? what if you had one every cm? how close would they have to be in order to detect ALL the information?
- What should each wave detector report? currently wet vs. dry (binary)? or average amount of time wet since the previous sample? or water depth at time of sample?
- Is sampling a matter of spatial coverage, or of time, or of range of values that can be measured at any given time?

Morrison, R. (2004). *Practical electronics: A self-teaching guide.* Hoboken, NJ: Wiley. Pp. 4-36, 65-69, 81-84, 206-208, 238-247. [Morrison2004.pdf]

Miller, G.A. (2007). *Electrical safety in the psychophysiology lab*. Unpublished manuscript. [safety.pdf]

National Institute for Occupational Safety and Health (2002). *Electrical safety: Safety and health for electrical trades: Student manual.* Cincinnati, OH: U.S. Department of Health and Social Services Centers for Disease Control and Prevention Publication No. 2002-123. Read pp. 6-8, 39, 42, 47-48. [PartsOf_2002_CDC_INOSH_ElectricalSafetyBooklet.pdf]

Kozak, M.J., & Miller, G.A. (1982). Hypothetical constructs versus intervening variables: A re-appraisal of the three-systems model of anxiety assessment. *Behavioral Assessment, 14,* 347-358. [KozakMiller1982.pdf]

Optional:

Hugdahl (1995), Chapter 3, pp. 49-62: The nervous system. [Hugdahl1995ch3.pdf] Read this if you do not have this background from other courses. Although it is in effect optional, you will be responsible for this material on the exams, unlike the readings marked "optional".

Putnam, L.E., Johnson, R., Jr., & Roth, W.T. (1992). Guidelines for reducing the risk of disease transmission in the psychophysiology laboratory. *Psychophysiology, 29,* 127-141. [PutnamJohnsonRoth1992.pdf]

4) Monday 10/17 Electronics, Filters, and Signal Processing; A Little Neuroscience; More Big Picture

>> Electronics Worksheet #2 due at start of class <<

Start on Electronics Worksheet #3 (due @ start of class 10/24)

Watch online prior to class: https://www.youtube.com/watch?v=GuCdsyCWmt8 =

ElectronMicroscopeVideoOfVinylLP_091716.mp4

OK to skip ahead to 4:20 to see vibrating stylus from an old record player--> moves magnets --> creates current --> transduce groove changes into sound

Listen for mentions of capacitance and consider how that might work…

Gazzaniga, M.S., Ivry, R.B., & Mangun, G.R. (2002). *Cognitive neuroscience: The biology of the mind, second edition*. New York: Norton. Read parts of Chapter 3, Gross and functional anatomy of cognition, pp. 62-76, 92-95. [GazzanigaIvryMangun2002_Chapter3partial.pdf] Read at least pp. 93-94 if you don't know the anatomy of the autonomic nervous system.

Soneira, R. (2010). Display myths: Shattered. *Maximum PC (July),* 45-51. [Soneira2010.pdf] This and optional readings may worry you about visual stimulus presentation in the lab.

Miller, G.A. (2010). Mistreating psychology in the decades of the brain. *Perspectives on Psychological Science, 5,* 716-743. [Miller_PPS_2010.pdf]

As you read, consider: what does it mean to call something "biological"? What does it mean to call something "a brain disorder"? What do you take for granted about such questions, and for what portions of what you take for granted can you articulate a justification? What bearing do your answers to those questions have on moral or legal responsibility for one's behavior? And on your work studying biological phenomena?

Optional:

Hugdahl (1995), Chapter 4, pp. 63-83: The brain. [Hugdahl1995ch4.pdf] Read this if you do not have this background from other courses.

Hugdahl (1995), Chapter 5, pp. 84-98: The autonomic nervous system. [Hugdahl1995ch5.pdf]

Gazzaniga, M.S., Ivry, R.B., & Mangun, G.R. (2002). *Cognitive neuroscience: The biology of the mind, second edition*. New York: Norton. Read parts of Chapter 3, Gross and functional anatomy of cognition, pp. 62-76, 92-95, if you do not have this background from other courses. [GazzanigaIvryMangun2002_Chapter3partial.pdf]

Vasey, M.W., & Thayer, J.F. (1987). The continuing problem of false positives in repeated measures ANOVA in psychophysiology: A multivariate solution. *Psychophysiology, 24,* 479-486. [VaseyThayer1987.pdf]

The next four readings discuss issues that are quite important if you use computer-presented visual stimuli in studies in which timing accuracy matters.

Luck, S.J. (2005), Chapter 8: Setting up an ERP lab (pp. 303-332; read just 322-332 on CRTs, LCDs, and stim timing). [Luck2005ch8.pdf]

Soneira, R. (2009). LCD response time and motion blur. [http://www.displaymate.com/LCD_Response_Time_ShootOut.htm accessed 6/14/10 & 10/09/16; Soneira_LCDdisplayTechnologyShootOut2009.pdf]

Wang, P., & Nikolic, D. (2011). An LCD monitor with sufficiently precise timing for research in vision. *Frontiers in Human Neuroscience, 5,* Article 85. [WangNikolic2011.pdf]

Elze, T., & Tanner, T.G. (2012). Temporal properties of liquid crystal displays: Implications for

vision science experiments. *PLoS ONE, 7,* e44048. [ElzeTanner2012.pdf]

5) Monday 10/24 Electronics, Filters, and Signal Processing

>> Electronics Worksheet #3 due at start of class <<

Start on Electronics Worksheet #4 (due @ start of class 10/31)

Watch online: https://www.youtube.com/watch?v=H1HLstfmbdU
= ScarboroughFairMachine_ppm_032510.flv illustrating the contrast between the sinusoidal regularity of the parts turning and the apparent irregularity of paddles & sound

Handout 5 = H5.pdf

Miller, G.A. *Decibels.* (2011). Unpublished manuscript. [Decibel10_gm_*.pdf]

Gratton, G. (2007). Biosignal processing. In Cacioppo et al. book (pp. 834-858). [GrattonBiosignalChapter2007.pdf]

Optional:

Wasserman, S., & Bockenholt, U. (1989). Boostrapping: Applications to psychophysiology. *Psychophysiology, 26,* 208-221. [WassermanBockenholt1989.pdf] Skim.

Good for home reviewing about sampling, bit depth, etc. (most accessible first):

https://www.youtube.com/watch?v=zC5KFnSUPNo = SamplingrateBitdepth_091716.mp4

https://www.youtube.com/watch?v=v7qjeUFxVwQ = AliasingAndNyquistQuick_091716.mp4

https://www.youtube.com/watch?v=-0rIU9FHiU0 = BitdepthSamplerate_091716.mp4

https://www.youtube.com/watch?v=W2-FP7twy8s = SamplingBitdepBitRateInterpolation_091716.mp4

6) Monday 10/31 Payday: Data Acquisition Circuits

>> Electronics Worksheet #4 due at start of class <<

Handout 6 = H6.pdf

Kaplan, F. (2010). Dulcet downloads. www.slate.com accessed 12/29/10. [Kaplan_DAC_122710.pdf] This will especially be of interest if you care about music sound quality, but in any case it applies your growing knowledge of analog-digital relationships.

Herrington, J.D., Sutton, B., & Miller, G.A. (2007). Data-storage formats in neuroimaging: Background and tutorial. In Cacioppo et al. book (pp. 859-866). New York: Cambridge University Press. [HerringtonSuttonMiller2007.pdf]

Miller, G.A., & Chapman, J.P. (2001). Misunderstanding analysis of covariance. *Journal of Abnormal Psychology, 110,* 40-48. [miller_chapman_JAbn2001.pdf]

Read this from the perspective of what psychophysiology calls the Law of Initial Value (e.g.,

Hugdahl, 1995, p. 38-39), specifically in terms of issues that arise in dealing with baseline differences in physiology as a function of group or condition. For early work on this issue in psychophysiology, track down Lorna Smith Benjamin's work on ANCOVA and the law of initial value in the early 1960s.

Optional:

Lykken, D., Rose, R., Luther, B., & Maley, M. (1966). Correcting psychophysiological measures for individual differences in range. *Psychological Bulletin, 66,* 481-484. The classic paper on "range correction". [LykkenRoseLutherMaley1966.pdf]

The next 2 readings provide an introduction to hemodynamic neuroimaging, more than enough to follow what we'll mention in this course.

Raichle, M.R. (2006). Functional neuroimaging: A historical and physiological perspective. In R. Cabeza & A. Kingstone (Eds.), *Handbook of functional neuroimaging of cognition* (pp. 3-20). Cambridge, MA: Bradford/MIT Press. [RaichleChapter2006.pdf]

If you read the optional Hugdahl chapter 1, compare it to this chapter - what difference did that decade make in psychophysiology? How have things changed in the most recent decade?

Poldrack, R.A., Mumford, J.A., & Nichols, T.E. (2011). *Handbook of functional MRI data analysis.* New York: Cambridge University Press. This is an excellent book. Chapter 1 provides a nice introduction if you have no background in MRI analysis. [PoldrackMumfordNichols_ch1_2011.pdf]

7) Monday 11/7 More Analog and Digital Filtering

Handout 7 = H7.pdf

Cook, E.W., III, & Miller, G.A. (1992). Digital filtering: Background and tutorial for psychophysiologists. *Psychophysiology, 29,* 350-367. [CookMiller1992.pdf]

Widmann, A., & Schröger, E. (2012). Filter effects and filter artifacts in the analysis of electrophysiological data. *Frontier in Psychology*. doi: 10.3389/fpsyg.2012.00233 [WidmannSchroger2012.pdf]

Optional:

Nitschke, J.B., Miller, G.A., & Cook, E.W. III. (1998). Digital filtering in EEG/ERP analysis: Some technical and methodological comparisons. In M. Eimer (Ed.), special issue of *Behavior Research Methods, Instruments, and Computers, 30,* 54-67. [NitschkeMillerCook1998.pdf]

Edgar, J.C., Stewart, J.L., & Miller, G.A. (2005). Digital filtering in EEG/ERP research. In T.C. Handy (Ed.), *Event-related potentials: A handbook* (pp. 85-113). Cambridge, MA: MIT Press. [EdgarStewartMillerFilter2005.pdf]

Luck, S.J. (2005) book, Chapter 5: Filtering (pp. 175-224). [Luck2005ch5.pdf]

Widmann, A., Schröger, E., & Maess, B. (2015). Digital filter design for electrophysiological data:

A practical approach. *Journal of Neuroscience Methods, 250,* 343-46. [WidmannSchrogerMaess2015.pdf]

8) Monday 11/14 A Quick Look at Electrodermal Recording Circuits;
The Cardiovascular System as a Metaphor for Basic Electronics

Lykken, D.T., & Venables, P.H. (1971). Direct measurement of skin conductance: A proposal for standardization. *Psychophysiology, 8,* 656-672. [LykkenVenables1971.pdf] Read 656-661, 664-672. Skip "Instrumentation..." section, but take a look at those circuit diagrams. We'll talk our way through them in class.

Berntson, G.G., Quigley, K.S., & Lozano, D. (2007). Cardiovascular psychophysiology. In Cacioppo et al. book (pp. 182-210). [Berntson_CardiovascularChapter2007.pdf]

Consider this passage, inspired by a submitted manuscript I recently reviewed:

"A pair of 4-mm Ag/AgCl electrodes were placed below the outer canthus of the left eye (Fridlund & Cacioppo, 1986) to measure EMG associated with startle blink, with a ground electrode behind the left ear. Impedance was < 5 KOhms. The EMG was amplified, rectified, and filtered to retain 10-500 Hz activity, notch-filtered at 60 Hz, sampled at 500 Hz, and digitized for 4 s beginning with stimulus onset."

- No mention of site preparation – ok?
- Why Ag/AgCl electrodes? What alternatives, with what consequences?
- Why 3 electrodes for 1 measurement? Why not 1, or 2, or 7….? 3rd one needed?
- What does "rectified" mean here? (Not "put right".)
- Is 500 Hz A/D sufficient? what would you recommend and why?
- Is 15 Kohms good? excessively high or low? what implications?
- No mention of prestim baseline – what impact of rectification on that? (If leaky-capacitor integration, or if high high-pass filter, signal will tend toward zero anyway. Else, if full-wave rectification, not removing baseline could be problematic.)

Optional:

Payne, A.F.H., Dawson, M.E., Schell, A.M., Singh, K., & Courtney, C.G. (2013). Can you give me a hand? A comparison of hands and feet as optimal anatomical sites for skin conductance recording. *Psychophysiology, 150*, 1065-1069. [PayneDawsonSchellSinghCourtney2013.pdf]

Iacono, W.G. (2007). Detection of deception. In Cacioppo et al. book (pp. 688-703). [IaconoChapter2007.pdf]

Fowles, D. C., Christie, M. J., Edelberg, R., Grings, W. W., Lykken, D. T., & Venables, P. H. (1981). Publication recommendations for electrodermal measurements. *Psychophysiology, 18*, 232–239. [Fowles1981.pdf]

Jennings, J.R., Berg, W.K., Hutchinson, J.S., Obrist, P., Porges, S., & Turpin, G. (1981). Publication guidelines for heart rate studies in man. *Psychophysiology, 18,* 226-231.

[Jennings1981.pdf] Skim.

Sherwood, A., Allen, M.T., Fahrenberg, J., Kelsey, R.M., Lovallo, W.R., & van Doornen, L.J. (1990). Methodological guidelines for impedance cardiography. *Psychophysiology, 27,* 1-23. [SherwoodImpedanceCardiographyGuidelines1990.pdf] Skim.

Shapiro, D., Jamner, L.D., Lane, J.D., Light, J.D., Myrtek, M., Sawada, Y., Steptoe, A. (1996). Blood pressure publication guidelines. *Psychophysiology, 33,* 1-12. [ShapiroBPguidelines1996.pdf] Skim.

Berntson, G.G., Bigger, J.T., Eckberg, D.L., Grossman, P., Kaufmann, P.G., Malik, M., Nagaraja, H.N., Porges, S.W., Saul, J.P., Stone, P.H., & van der Molen, M.W. (1997). Heart rate variability: Origins, methods, and interpretive caveats. *Psychophysiology, 34,* 623-648. [Berntson1997.pdf] Skim.

Allen, J.J.B., Chambers, A.S., & Towers, D.N. (2007). The many metrics of cardiac chronotropy: A pragmatic primer and a brief discussion of metrics. *Biological Psychology, 74,* 243-262. [AllenChambersTowers2007.pdf] Skim – survey the variety of measures available.

9) Monday 11/21 Oscillations & Connectivity: Some Electromagnetic Options

Makeig, S., Debener, S, Onton, J., & Delorme, A. (2004). Mining event-related brain dynamics. *Trends in Cognitive Sciences, 8,* 204-210. [MakeigDebenerOntonDelorme2004.pdf]

Bastiaansen, M., Mazaheri, A., & Jensen, O. (2012). Beyond ERPs: Oscillatory neuronal dynamics. In Luck & Kappenman book (pp. 31-49). [BastiaansenMazaheriJensen_2012.pdf]

Popov, T., Wienbruch, C., Meissner, S., Miller, G.A., & Rockstroh, B. (2015). A mechanism of deficient inter-regional neural communication in schizophrenia. *Psychophysiology, 52,* 648-656. doi: 10.1111/psyp.12393. [PopovWienbruchMeissnerMillerRockstroh2015.pdf]

Optional:

Popov, T., & Popova, P. (2015). Same clock, different time read-out: Spontaneous brain oscillations and their relationship to deficient coding of cognitive content. *NeuroImage, 119,* 316-324. [PopovPopova2015.pdf]

10) Monday 11/28 Connectivity: Some Hemodynamic Options Including Integration with via Optical, MEG, and EEG Neuroimaging Methods; Catch-up/Wrap-up

Silton, R.L., Heller, W., Towers, D.N., Engels, A.S., Edgar, J.C., Spielberg, J.M., Sass, S.M., Stewart, J.L., Sutton, B.P., Banich, M.T., & Miller, G.A. (2011). Depression and anxiety distinguish frontocingulate cortical activity during top-down attentional control. *Journal of Abnormal Psychology, 120,* 272-285. [Silton_JAbn_2011.pdf]

Spielberg, J.M., Miller, G.A., Heller, W., & Banich, M.T. (2015). Flexible brain network

reconfiguration supporting inhibitory control. *Proceedings of the National Academy of Sciences, 112,* 10020-10025. [SpielbergMillerHellerBanich_PNAS_2015.pdf]

Optional:

Burdwood, E.N., Infantolino, Z.P., Crocker, L.D., Spielberg, J.M., Banich, M.T., Miller, G.A., & Heller, W. (In press). Resting-state functional connectivity differentiates anxious apprehension, anxious arousal, and depression. *Psychophysiology*. [BurdwoodEtAl_PublicAccess_InPress.pdf]

Luck, S.J. (1999). Direct and indirect integration of event-related potentials, functional magnetic resonance images, and single-unit recordings. *Human Brain Mapping, 8,* 115-120. [Luck_1999.pdf]

Brookes, M.J., O'Neill, G.C., Hall, E.L., Woolrich, M.W., Baker, A., Corner, S.P., Robson, S.E., Morris, P.G. and Barnes, G.R. (2014). Measuring temporal, spectral and spatial changes in electrophysiological brain network connectivity. *NeuroImage, 91,* 282-299. The intro is worth reading - argues the need for higher time resolution than fMRI provides in order to get at brain states.

Weinberger, D.R., & Radulescu, E. (2016). Finding the elusive psychiatric "lesion" with 21st-century neuroanatomy: A note of caution. *American Journal of Psychiatry, 173,* 27-33. [WeinbergerRadulescu2016.pdf]

Exam **TBD**

Selected other resources…I can provide .pdfs if interested

Guidelines papers from the Society for Psychophysiological Research:
https://www.sprweb.org/guidelines-papers/

About Nyquist, sampling, aliasing…
AmazingPendulumWaveEffect_YouTube_144p_051216.flv
http://www.michaelbach.de/ot/mot-wagonWheel/index.html - good to experiment with
https://www.youtube.com/watch?v=VNftf5qLpiA = Valvano_WagonWheelEffect_100916.mp4
https://www.youtube.com/watch?v=yWqrx08UeUs = SamplingAliasingNyquistTheorem_091716.mp4 (start at 5:50 & 8:00)
https://www.youtube.com/watch?v=XoVhNhi76Qk = DigitalAudio101AliasingExplained.mp4 (a bit advanced, possibly of interest)

Oscillations
http://www.newyorker.com/news/news-desk/video-beach-creatures
https://www.youtube.com/watch?v=HSKyHmjyrkA

https://www.youtube.com/watch?v=hHTuXe1rZrQ

Miscellany

Clayson, P.E., & Miller, G.A. (In press.). ERP Reliability Analysis (ERA) Toolbox: An open-source toolbox for analyzing the reliability of event-related brain potentials. *International Journal of Psychophysiology.* [ClaysonMiller_RelRev_CorrectedProof_IJP_2016.pdf]

Donchin, E., & Heffley III, E.F. (1978). Multivariate analysis of event-related potential data: A tutorial review. In D.A. Otto (Ed.), *Multidisciplinary perspectives in event-related brain potential research* (pp. 555-572). Washington, D.C.: Environmental Protection Agency. [DonchinHeffley1978.pdf]

Do not plan to understand all of this material the first time, but it is worth investing time in. Its applicability is far broader than ERPs. I advise my own students to re-read it annually throughout grad school

Gratton, G., & Fabiani, M. (2010). Fast optical imaging of human brain function. *Frontiers in Human Neuroscience, 4,* 1-9. [GrattonFabiani2010.pdf]

Keil, A., Debener, S., Gratton, G., Junghöfer, M., Kappenman, E.S., Luck, S.J., Luu, P., Miller, G.A., & Yee, C.M. (2014). Committee report: Publication guidelines and recommendations for studies using electroencephalography and magnetoencephalography. *Psychophysiology, 51,* 1-21.

Miller, G.A., Lutzenberger, W., & Elbert, T. (1991). The linked-reference issue in EEG and ERP recording. *Journal of Psychophysiology, 5,* 273-276. [MillerLutzenbergerElbert1991.pdf]

Pizzagalli, D.A. (2007). Electroencephalography and high-density electrophysiological source localization. In Cacioppo et al. book (pp. 56-84). [PizzagalliChapter2007.pdf]

Towers, D.N., & Allen, J.J.B. (2009). A better estimate of the internal consistency reliability of frontal EEG asymmetry scores. *Psychophysiology, 46,* 132-142. [TowersAllen2009.pdf]

Urbach, T.P., & Kutas, M. (2006). Interpreting event-related brain potential f(ERP) distributions: Implications of baseline potentials and variability with application to amplitude normalization by vector scaling. *Biological Psychology, 72,* 333-343. [UrbachKutas2006.pdf]