**Quantitative Neuroscience Core**

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| *Instructor* | Joshua Gold | jigold@pennmedicine.upenn.edu |
| *TA* | Diego Dávila | Diego.Davila@pennmedicine.upenn.edu |
| *Required meeting times* | MWF | 9–10 am |
| *Optional discussion section/office hours* | Thurs | 12-1 pm (Barchi) |
| *Meeting location* | Class of '62 Auditorium |  |
| *Up-to-date syllabus* | [here](https://canvas.upenn.edu/courses/1358934/files/folder/Courses/Quantitative%20Neuro%20Core) |  |

*Lecture recordings are here:* <https://mediasite.med.upenn.edu/mediasite/Channel/bcaaf0fbc98a4f02abdc82d760877fef5f/browse/null/oldest/null/0/e737e2cf9b2e45fd919a57bebf66b5a114>

**Introduction**

This course is designed to be an overview of quantitative approaches used for rigorous and reproducible neuroscience research. This course does not cover statistics in a traditional way, in the sense that we will not provide a comprehensive survey of statistical tests, nor will we dive very deeply into formal mathematical derivations of those tests (information about such things can be found in textbooks and all over the web). Instead, we will focus on teaching you to apply quantitative approaches to your thinking about neuroscience research from beginning to end, including defining clear hypotheses; designing experiments to test those hypotheses; collecting, visualizing, analyzing, and interpreting data in reference to those hypotheses; and keeping effective and transparent records at each stage to ensure rigor and reproducibility.

There are two main components to the course. The first component consists of a series of modules, each of which is designed to use a specific example from neuroscience to illustrate a set of quantitative approaches and tools. The second component consists of group projects that focus on designing and implementing quantitative analyses for existing data sets (e.g., from your rotation project).

**Learning Objectives**

**1) Develop good habits for transparent, reproducible science**. Transparency is the idea that none of your data or methods should be hidden. Reproducibility is the idea that you should be designing, conducting, and analyzing experiments in a way that maximizes the probability that someone else doing the same experiments would come to the same conclusions. To support these ideas, we will incorporate into the course the use of several on-line tools that, even if you do not end up using these particular tools in your own research, will help establish good habits for record keeping (we will use LabArchives electronic notebooks, [https://researchnotebooks.upenn.edu](https://researchnotebooks.upenn.edu/)), version control for code (we will use GitHub, [https://github.com](https://github.com/)), and data storage (we will use PennBox: [https://upenn.app.box.com](https://upenn.app.box.com/)). Please register the names/links for your accounts [here](https://docs.google.com/spreadsheets/d/1Eo-Z0maK5aarF4vIbOVTtZphH3AQlK79BR2AklTe1zc/edit#gid=0).

**2) Learn to think about statistics in the context of good experimental design**. The question “what statistical test should I use?” can be answered only after answering more basic questions, like “what are the alternative hypotheses that I am testing?”and “how well does my experimental design allow me to distinguish those hypotheses?”

**3) Learn foundations of statistical reasoning, particularly how to think about randomness using probability distributions**. Even the most sophisticated statistical procedures are ultimately about distinguishing signal from noise. This ability depends on understanding what is meant by “noise”, or randomness. The primary mathematical tool for quantifying and manipulating randomness is the probability distribution, which describes the probability of obtaining all possible values of a quantity of interest (e.g., the outcome of an experiment). We therefore will spend some time learning about probability distributions and then build on those concepts to better understand how to use probability distributions to make inferences.

**4) Learn to visualize your data effectively to lay bare your statistical reasoning**. Ultimately your ability to convince other people that you have a robust finding will not depend on the results of a statistical test but rather on your ability to show the finding in a clear and compelling way; that is, in a way that is transparent in terms of what you measured, clearly reflects the experimental design, and illustrates both the signal and noise that you found. We will focus on specific ways to visualize data effectively throughout the course.

**Course Resources**

This course is just one component of a more comprehensive training program that we are developing that covers quantitative approaches in neuroscience. A centerpiece of this training program is a curated [list of resources](file:////courses/1358934/pages/quantitative-neuroscience-resources) and [collection of readings](file:////courses/1358934/files/folder/Courses/Quantitative%2520Neuro%2520Core/Readings). Our goal in this course is to cover some of these materials in detail but more generally get you familiar with some of the key ideas so you can continue to return to these materials when you need them in your research.

We also will be using this [discussion board](file:////courses/1358934/discussion_topics/7745541) (available only to current course participants) to give you an opportunity to ask and answer questions in a supportive environment.

**Coding**

Many of the topics covered in this course are implemented in either [Matlab](https://www.mathworks.com/" \t "_blank) or [Python](https://www.python.org/) (course materials are [here](https://github.com/PennNGG/Statistics/)). Ask anyone who uses either language and they will doubtless give you long, passionate explanations of why one is better than the other, but here suffice it to say that both are used in research labs and so we want to give you exposure to both. In class we will mostly run the Python-based demonstrations, because they are implemented in a [web-based notebook format called Colaboratory](https://colab.research.google.com/notebooks/intro.ipynb?utm_source=scs-index) that is easy for even non-programmers to use. You can choose which language(s) to use for your course-based exercises and projects.

If you do not already know how to program in either language, you should still be able to follow along with the logic and learn a bit as you go. We will provide some instruction, and it is reasonable to assume that you could go from a complete novice to someone who can write some basic code. However, do not expect the course alone to teach you how to program. Here are some resources that can help you in that regard:

**Resources for Learning Matlab**

* From Mathworks: [Getting started](https://www.mathworks.com/help/matlab/getting-started-with-matlab.html)
* Coursera: [Learn Matlab](https://www.coursera.org/learn/matlab)
* Wallisch et al, *[Matlab for Neuroscientists](https://www.sciencedirect.com/book/9780123838360/matlab-for-neuroscientists" \t "_blank)*
* The summer Matlab course offered by the NGG

**Resources for Learning Python**

* From Python.org: [Python for beginners](https://www.python.org/about/gettingstarted/)
* Coursera: [Python courses](https://www.coursera.org/courses?query=python)
* Kaggle: [Introduction to Programming in Python](https://www.kaggle.com/learn/intro-to-programming), [Learning Python](https://www.kaggle.com/learn/python)
* A useful [refresher for basic Python syntax](https://learnxinyminutes.com/docs/python/)

**Grading**

Grades are based on: 1) completion of homework assignments, including posting your results to the appropriate notebook and/or repository (20%); 2) class participation, including engagement in discussions (20%); and 2) a final project involving three in-class presentations (15% each) and electronic records of analysis strategies and code (15%).

For our philosophy of grading, see [here](https://www.med.upenn.edu/ngg/handbook.html).

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| **PART 1: FOUNDATIONS** | | | |  |
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| **Fri** | **2-Sep** |  | **Introduction I: Overview, Goals, and Record Keeping** | **Read and be prepared to discuss:** |
|  |  |  |  | [Record Keeping: Introduction](https://canvas.upenn.edu/courses/1358934/pages/record-keeping-introduction) |
|  |  |  |  | [Record Keeping: Laboratory Notebooks](https://canvas.upenn.edu/courses/1358934/pages/record-keeping-laboratory-notebooks) |
|  |  |  |  | [Record Keeping: Algorithms](https://canvas.upenn.edu/courses/1358934/pages/record-keeping-algorithms) |
|  |  |  |  | [Record Keeping: Data](https://canvas.upenn.edu/courses/1358934/pages/record-keeping-data) |
|  |  |  |  | **Sign up for the following accounts (if you haven't already) and confirm on this spreadsheet:** |
|  |  |  |  | [QNX 2022 Record Keeping](https://docs.google.com/spreadsheets/d/1Eo-Z0maK5aarF4vIbOVTtZphH3AQlK79BR2AklTe1zc/edit#gid=0) |
|  |  |  |  | [LabArchives (through Penn)](https://researchnotebooks.upenn.edu/) |
|  |  |  |  | [GitHub](https://github.com/) |
|  |  |  |  | [PennBox (through Penn)](https://www.isc.upenn.edu/pennbox) |
|  |  |  |  | **Come prepared to discuss from your own lab experiences an example of either: 1) good record keeping, or 2) poor record keeping** |
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| **Mon** | **5-Sep** |  | **LABOR DAY -- NO CLASS** |  |
|  |  |  |  |  |
| **Wed** | **7-Sep** |  | **Introduction II: Inference and Statistics** | **Readings:** |
|  |  |  |  | [1. Platt, J.R. (1964) Strong Inference: Certain systematic methods of scientific thinking may produce much more rapid progress than others. Science146, 347-353.](https://canvas.upenn.edu/courses/1358934/files/folder/Courses/Quantitative%20Neuro%20Core/Readings/Strong%20Inference?preview=73414131) |
|  |  |  |  | **Come prepared to discuss from your own lab experiences, or from a study you have learned/read about, an example of either: 1) strong inference, or 2) not strong inference** |
|  |  |  |  | [2. Kass, R.E. (2011) Statistical Inference: The Big Picture. Statistical Science 26(1).](https://canvas.upenn.edu/courses/1358934/files/folder/Courses/Quantitative%20Neuro%20Core/Readings/General/Overviews?preview=80296922) |
|  |  |  |  | **Come prepared to describe from the paper: a) a topic that you have already learned/understand well, and b) a topic that is new to you and/or is not clear from the description in the paper.** |
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| **Fri** | **9-Sep** |  | **Introduction III: Frequentist versus Bayesian Approaches** | **Go through the following tutorial and complete exercises 1 and 2. Post your answers to GitHub.** |
|  |  |  |  | [Frequentist versus Bayesian approaches](https://github.com/PennNGG/Quantitative-Neuroscience/blob/master/Concepts/Python/Frequentist%20Versus%20Bayesian%20Approaches.ipynb) |
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| **Mon** | **12-Sep** |  | **Data Visualization I: Principles (Dávila)** |  |
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| **Wed** | **14-Sep** |  | **Data Visualization II: Examples (Dávila)** | **Find a figure/graph from a paper you think displays the distribution of their data well or poorly. Post it in the Canvas course discussion.** |
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| **Fri** | **16-Sep** |  | **Probability Distributions I: Concepts** | **Go through the following tutorials, then: 1) find a paper that shows data thought to come from one of these distributions, and 2) write code to simulate data that (roughly) match the distribution shown in the paper. Post your answers to GitHub.** |
|  |  |  |  | [Samples and Populations](https://github.com/PennNGG/Quantitative-Neuroscience/blob/master/Concepts/Samples%20and%20Populations.ipynb) |
|  |  |  |  | [Probability Distributions Overview](https://github.com/PennNGG/Quantitative-Neuroscience/blob/master/Probability%20Distributions/Overview.ipynb) |
|  |  |  |  | [Bernoulli Distribution](https://github.com/PennNGG/Quantitative-Neuroscience/blob/master/Probability%20Distributions/Python/Bernoulli.ipynb) |
|  |  |  |  | [Binomial Distribution](https://github.com/PennNGG/Quantitative-Neuroscience/blob/master/Probability%20Distributions/Python/Binomial.ipynb) |
|  |  |  |  | [Exponential Distribution](https://github.com/PennNGG/Quantitative-Neuroscience/blob/master/Probability%20Distributions/Python/Exponential.ipynb) |
|  |  |  |  | [Gaussian (Normal) Distribution](https://github.com/PennNGG/Quantitative-Neuroscience/blob/master/Probability%20Distributions/Python/Gaussian%20(Normal).ipynb) |
|  |  |  |  | [Poisson Distribution](https://github.com/PennNGG/Quantitative-Neuroscience/blob/master/Probability%20Distributions/Python/Poisson.ipynb) |
|  |  |  |  | [Student's t Distribution](https://github.com/PennNGG/Quantitative-Neuroscience/blob/master/Probability%20Distributions/Student's%20t.ipynb) |
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| **Mon** | **19-Sep** |  | **Probability Distributions II: Binomial Distribution Case Study** | **Complete the exercises from the Neuroscience Example (“Quantal release”) case study in the Binomial distribution tutorial and post your answers to GitHub** |
|  |  |  |  | [Binomial Distribution](https://github.com/PennNGG/Quantitative-Neuroscience/blob/master/Probability%20Distributions/Python/Binomial.ipynb) |
|  |  |  |  |  |
| **Wed** | **21-Sep** |  | **Probability Distributions III: Confidence Intervals and Bootstrapping** | **Go through the following tutorial, then complete the Exercises and post your answers to GitHub:** |
|  |  |  |  | [Confidence Intervals and Bootstrapping](https://github.com/PennNGG/Quantitative-Neuroscience/blob/master/Concepts/Confidence%20Intervals%20and%20Bootstrapping.ipynb) |
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| **Fri** | **23-Sep** |  | **Two-Sample Inference I: Experimental Design and Power Analysis** | **Read and be prepared to discuss:** |
|  |  |  |  | [Button et al (2013), Power failure: why small sample size undermines the reliability of neuroscience](https://canvas.upenn.edu/courses/1358934/files/folder/Courses/Quantitative%20Neuro%20Core/Readings/Error%20Types%2C%20P-values%2C%20False-Positive%20Risk%2C%20and%20Power%20Analysis/Power%20Analysis?preview=98917936) |
|  |  |  |  | **Go through the following tutorial, then complete the Exercises and post your answers to GitHub:** |
|  |  |  |  | [Error Types, P-Values, False-Positive Risk, and Power Analysis](https://github.com/PennNGG/Quantitative-Neuroscience/blob/master/Concepts/Python/Error%20Types%2C%20P-Values%2C%20False-Positive%20Risk%2C%20and%20Power%20Analysis.ipynb) |
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| **Mon** | **26-Sep** |  | **Two-Sample Inference II: Parametric Tests and Multiple Comparisons** | **Go through the following tutorials, then complete the Exercises and post your answers to GitHub:** |
|  |  |  |  | [t-tests](https://github.com/PennNGG/Quantitative-Neuroscience/blob/master/Hypothesis%20Testing/Python/t-Tests.ipynb) |
|  |  |  |  | [Multiple comparisons](https://github.com/PennNGG/Quantitative-Neuroscience/blob/master/Concepts/Python/Multiple%20Comparisons.ipynb) |
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| **Wed** | **28-Sep** |  | **Two-Sample Inference III: Nonparametric Tests** | **Complete and be prepared to discuss this Colab tutorial:** |
|  |  |  |  | [Simple Non-Parametric Tests](https://github.com/PennNGG/Quantitative-Neuroscience/blob/master/Hypothesis%20Testing/Python/Simple%20Non-Parametric%20Tests.ipynb) |
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| **Fri** | **30-Sep** |  | **Measures of Association I: Correlation** | **Go through the following tutorials, then complete the parametric correlation coefficient exercises and post your answers to GitHub.** |
|  |  |  |  | [Measures of association](https://github.com/PennNGG/Quantitative-Neuroscience/blob/master/Measures%20of%20Association/Overview.ipynb) |
|  |  |  |  | [Parametric correlation coefficient](https://github.com/PennNGG/Quantitative-Neuroscience/blob/master/Measures%20of%20Association/Parametric%20Correlation%20Coefficient.ipynb) |
|  |  |  |  | [Nonparametric correlation coefficient](https://github.com/PennNGG/Quantitative-Neuroscience/blob/master/Measures%20of%20Association/Nonparametric%20Correlation%20Coefficient.ipynb) |
|  |  |  |  | **Optional: Review the code in the NGG GitHub Repository under "Examples/LC-Pupil/" that was used to generate Fig. 3 of Joshi et al.** |
|  |  |  |  |  |
| **Mon** | **3-Oct** |  | **Measures of Association II: "Nonsense correlations"** | **Read and be prepared to discuss:** |
|  |  |  |  | [Nonsense Correlations in Neuroscience](https://canvas.upenn.edu/courses/1358934/files/folder/Courses/Quantitative%20Neuro%20Core/Readings/Correlations?preview=111122192) |
|  |  |  |  | Code to generate figures is |
|  |  |  |  | [here](https://colab.research.google.com/github/kdharris101/nonsense-correlations/blob/main/nonsense.ipynb#scrollTo=LhSS1xJiBN8b) |
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| **Wed** | **5-Oct** |  | **Measures of Association III: Simple Linear Regression** | **Gol through the following tutorials, then complete the linear regression exercises and post your answers to GitHub.** |
|  |  |  |  | [Measures of association](https://github.com/PennNGG/Quantitative-Neuroscience/blob/master/Measures%20of%20Association/Overview.ipynb) |
|  |  |  |  | [Simple linear regression](https://github.com/PennNGG/Quantitative-Neuroscience/blob/master/Measures%20of%20Association/Linear%20Regression.ipynb) |
|  |  |  |  |  |
| **Fri** | **7-Oct** |  | **QNC Modeling I: LATER Model Case Study** | **Read and be prepared to discuss:** |
|  |  |  |  | [Noorani (2014)](https://www.frontiersin.org/articles/10.3389/fnint.2014.00067/full) |
|  |  |  |  | **Some more readings just for fun:** |
|  |  |  |  | [RT at Penn I](https://www.sas.upenn.edu/psych/history/cattelltext.htm) |
|  |  |  |  | [RT at Penn II](https://www.sas.upenn.edu/~saul/rt.experimentation.pdf) |
|  |  |  |  | [RT at Penn III](https://www.physics.upenn.edu/reactiontime/) |
|  |  |  |  |  |
| **Mon** | **10-Oct** |  | **QNC Modeling II: RT Data Visualization** | **Run the Matlab tutorials in the NGG GitHub Repository under "Examples/LATER model/laterTutorial\_plot\*"** |
|  |  |  |  | [Repository link](https://github.com/PennNGG/Statistics.git) |
|  |  |  |  |  |
| **Wed** | **12-Oct** |  | **QNC Modeling III: Model Fitting** | **Run the Matlab tutorials in the NGG GitHub Repository under "Examples/LATER model/laterTutorial\_modelFits and laterTutorial\_modelParameters"** |
|  |  |  |  | [Repository link](https://github.com/PennNGG/Statistics.git) |
|  |  |  |  |  |
| **PART 2: APPLICATIONS (STUDENT PRESENTATIONS)** | | | | |
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| **Fri** | **14-Oct** |  | **PRESENTATION 1: HYPOTHESES AND EXPERIMENTAL DESIGN** | |
|  |  |  |  |  |
| **Mon** | **17-Oct** |  |  |  |
| **Wed** | **19-Oct** |  |  |  |
| **Fri** | **21-Oct** |  |  |  |
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| **Mon** | **24-Oct** |  |  |  |
| **Wed** | **26-Oct** |  |  |  |
| **Fri** | **28-Oct** |  |  |  |
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| **Mon** | **31-Oct** |  |  |  |
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| **Wed** | **2-Nov** |  | **PRESENTATION 2: DATA VISUALIZATION** | |
| **Fri** | **4-Nov** |  |  |  |
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| **Mon** | **7-Nov** |  |  |  |
| **Wed** | **9-Nov** |  |  |  |
| **Fri** | **11-Nov** |  |  |  |
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| **Mon** | **14-Nov** |  |  |  |
| **Wed** | **16-Nov** |  |  |  |
| **Fri** | **18-Nov** |  |  |  |
|  |  |  |  |  |
| **Mon** | **21-Nov** |  | **PRESENTATION 3: HYPOTHESIS TESTING** | |
| **Wed** | **23-Nov** |  |  |  |
| **Fri** | **25-Nov** |  | **THANKSGIVING -- NO CLASS** |  |
|  |  |  |  |  |
| **Mon** | **28-Nov** |  |  |  |
| **Wed** | **30-Nov** |  |  |  |
| **Fri** | **2-Dec** |  |  |  |
|  |  |  |  |  |
| **Mon** | **5-Dec** |  |  |  |
| **Wed** | **7-Dec** |  |  |  |
| **Fri** | **9-Dec** |  |  |  |