

# NEUROSCIENCE

**Directors of undergraduate studies:** Damon Clark (neuroscience.dus@yale.edu) (MCDB), YSB C148; Steve Chang (steve.chang@yale.edu) (Psychology), 100 College St.; neuroscience.yale.edu

Neuroscience aims to understand how the brain produces the mind and behavior, with the goal of advancing human understanding, improving physical and mental health, and optimizing performance. This entails a broad, interdisciplinary effort that spans from molecules to minds. At one end, biology, chemistry, and physics are improving our understanding of the molecular and cellular mechanisms of neuronal signaling and development. At the other end, psychology, psychiatry, and computer science link neural processes and systems to the mind and behavior. At all levels, the rich array of methods and data analysis depends on a strong foundation in the basic sciences, mathematics, statistics, and computer science.

## PREREQUISITES

The foundational biology courses required of all Neuroscience majors are BIOL 101, 102, 103, and 104. All majors must also complete one of the following: PSYC 200, S&DS 103, 105, 230, 238.

## PLACEMENT PROCEDURES

When declaring the major, students are encouraged to send a completed Neuroscience major worksheet to the department registrar (neuroscience.registrar@yale.edu) to help with advising. We encourage all majors to take the Human Brain (NSCI 160) and Neurobiology (NSCI 320) as early as possible since these courses provide foundations for the NSCI curriculum and independent research.

## REQUIREMENTS OF THE MAJOR

A minimum of 18.5 credits is required, including the prerequisites (5 courses for 3 credits), 15 lecture or seminar courses (which include the senior requirement), and one laboratory, as follows:

1. Two Neuroscience foundation courses, NSCI 160 and 320.
2. One Neuroscience lab (YC NSCI: Neuroscience Lab) chosen from NSCI 228L, 229L, 240, 258, 260, 270, 321L; PSYC 238.
3. Eleven electives from the following core groupings. Students may search for approved courses using the attributes indicated in each core grouping. The complete list of approved courses can be found on the NSCI website.
  - minimum of 2 courses from *Systems/Circuits/Behavior Core* (YC NSCI: Systems/Circuit/Behav)
  - minimum of 2 courses from *Molecular/Cellular/Biological Core* (YC NSCI: Molecular/Cell/Biol)
  - minimum of 1 course from *Quantitative Core* (YC NSCI: Quantitative)
  - minimum of 1 course from *Computational Core* (YC NSCI: Computational)

- minimum of 1 course from *Basic Allied Core* (YC NSCI: Basic Allied Core)
- no more than 2 courses from *Other Allied Core* (YC NSCI: Other Allied)

**Credit/D/Fail** No course taken Credit/D/Fail may be counted toward the major, including prerequisites.

### SENIOR REQUIREMENT

In addition to the course requirements described above, all students must satisfy a senior requirement undertaken during the senior year. All students must fill out a checklist of requirements and go over it with the undergraduate registrar by the spring term of the junior year.

**B.S. degree program** The B.S. degree program requires two-course credits of empirical research, NSCI 490 and 491. These courses are only available to Neuroscience seniors and receive a letter grade. Students are expected to spend at least 10 hours per week in the laboratory, to complete written assignments, and to give a presentation. In addition to time in the lab, and as part of NSCI 490 and 491, students are expected to attend a semi-regular capstone seminar, hear guest speakers, and discuss senior work progress with their peers and the directors of undergraduate studies (DUSs.) Research can be conducted over original, archival, or consortium data sets. Written assignments include a short research plan due at the beginning of the fall term, a grant proposal due at the end of the fall term, and a final report due at the end of the spring term. Students should pursue the same research project for two terms, with the grant proposal guiding and serving as the background for the research and final report. Seniors are also required to present their research in the spring term at a poster session. Students should find a research laboratory during the term preceding the research. Yale College does not grant academic credit for summer research unless the student is enrolled in an independent research course in Yale Summer Session. To register for NSCI 490 and 491, students must submit a form and the research plan with a bibliography, approved by the faculty research adviser and a DUS, by the end of the first week of classes.

**B.A. degree program** The B.A. degree program requires two course credits in nonempirical research, NSCI 480 and 481; or one credit in nonempirical research, NSCI 480 or 481, and one credit in empirical research, NSCI 490 or 491. These courses are only open to Neuroscience seniors and receive a letter grade. Under faculty supervision, for NSCI 480 or 481, students are required to conduct original research for at least 10 hours per week that does not involve direct interaction with data, such as developing a theory or conducting a meta-analysis to synthesize existing findings. A literature review without novel intellectual contributions is not adequate. Written assignments include a short research plan due at the beginning of the fall term, a literature review or draft theoretical paper due at the end of the fall term, and a theoretical paper due at the end of the spring term. Seniors are also required to present their research in the spring term at a poster session. To register, students must submit a form and the research plan with a bibliography, approved by the faculty adviser and a DUS, by the end of the first week of classes.

More detailed guidelines, forms, and deadline information are available on the program website.

## ADDITIONAL INFORMATION

**Independent research courses before senior year.** The only independent research courses available to students prior to senior year are NSCI 470, 471. These courses are graded Pass/Fail and count toward the thirty-six credits required for the bachelor's degree, but they do not substitute for any NSCI major requirement, including the senior requirement. Independent research courses do not satisfy the lab requirement for the NSCI major. These courses are for non-Senior Neuroscience students only.

## ADVISING

Due to overlap in the major course requirements, the Neuroscience major should not be combined with a second major in Molecular, Cellular and Developmental Biology or Psychology.

**Program advisers** Each term, students should update their Neuroscience major worksheet and then meet with their assigned faculty adviser to discuss their schedule and review their worksheet. These documents should then be submitted to the Neuroscience registrar for DUS review and approval. For questions concerning credits for courses taken at other institutions, or courses not listed in Yale Course Search, students should contact the Neuroscience registrar.

## SUMMARY OF MAJOR REQUIREMENTS

**Prerequisites** BIOL 101, 102, 103, and 104; and one of PSYC 200, S&DS 103, 105, 230, 238

**Number of courses** 18.5 credits (including prereqs and senior req)

**Specific courses required** 2 neuroscience foundation courses, NSCI 160 and 320

**Distribution of courses** *B.S. or B.A.* — 1 lab course; 11 electives including at least: 2 Systems/Circuits/Behavior Core courses, 2 Molecular/Cellular/Biological Core courses, 1 Quantitative Core course, 1 Computational Core course, 1 Basic Allied Core course, and no more than 2 Other Allied Core courses

**Senior requirement** *B.S.* — 2 empirical research courses, NSCI 490 and 491; *B.A.* — 2 nonempirical research courses, NSCI 480 and 481, or 1 empirical research course (NSCI 490 or 491) and 1 nonempirical research course (NSCI 480 or 481)

## Prerequisites

5 courses for 3 credits

- BIOL 101
- BIOL 102
- BIOL 103
- BIOL 104
- 1 of PSYC 200, S&DS 103, S&DS 105, S&DS 230, S&DS 238

## Requirements for the B.S. Degree

19 courses (18.5 credits), including the senior requirement and the prerequisites

- NSCI 160
- NSCI 320
- 1 lab course (half-credit or full credit)
- 11 electives (see Overview) to include
  - 2 Systems/Circuits/Behavior Core courses
  - 2 Molecular/Cellular/Biological Core courses
  - 1 Quantitative Core course
  - 1 Computational Core course
  - 1 Basic Allied Core course
  - no more than 2 Other Allied Core courses
- NSCI 490 and NSCI 491 (empirical research courses)

### **Requirements for the B.A. Degree**

19 courses (18.5 credits), including the senior requirement and the prerequisites

- NSCI 160
- NSCI 320
- 1 lab course (half-credit or full credit)
- 11 electives (see Overview) to include
  - 2 Systems/Circuits/Behavior Core courses
  - 2 Molecular/Cellular/Biological Core courses
  - 1 Quantitative Core course
  - 1 Computational Core course
  - 1 Basic Allied Core course
  - no more than 2 Other Allied Core courses
- NSCI 480 and NSCI 481 (nonempirical research courses), or 1 empirical research course (NSCI 490 or NSCI 491) and 1 nonempirical research course (NSCI 480 or NSCI 481)

Neuroscience aims to understand how the brain produces the mind and behavior, with the goal of advancing human understanding, improving physical and mental health, and optimizing performance. This entails a broad, interdisciplinary effort that spans from molecules to minds. At one end, biology, chemistry, and physics are improving our understanding of the molecular and cellular mechanisms of neuronal signaling and development. At the other end, psychology, psychiatry, and computer science link neural processes and systems to the mind and behavior. At all levels, the rich array of methods and data analysis depends on a strong foundation in the basic sciences, mathematics, statistics, and computer science.

Jointly hosted by the Molecular, Cellular, and Developmental Biology department and the Psychology department, the Neuroscience major provides excellent scientific preparation for graduate school, medical school and the health professions, and law school, as well as a wide range of professional careers in the biological sciences, technology, business, law, education, journalism, and public policy, to name a few.

As prerequisites, prospective majors should take the foundational biology sequence BIOL 101, 102, 103, and 104 in their first year and a course in statistics from PSYC 200, S&DS 103, 105, 230, 238 in their first or second year. Students can join the major with two of these three credits, as long as they have also completed one of the two foundational courses.

Indeed, prospective majors are encouraged to take the foundational course NSCI 160 as early as possible, as it is a requirement for the major, does not have prerequisites, and provides a general sense of the field of neuroscience. This course is also appropriate for nonmajors interested in neuroscience.

For additional information, visit the program website.

## FACULTY OF THE NEUROSCIENCE MAJOR

**Professors** †Amy Arnsten (*School of Medicine, Psychology*), Ty Cannon (*Psychology*), John Carlson (*Molecular, Cellular, and Developmental Biology*), Marvin Chun (*Psychology*), Damon Clark (*Molecular, Cellular, and Developmental Biology*), Thierry Emonet (*Molecular, Cellular, and Developmental Biology*), Paul Forscher (*Molecular, Cellular, and Developmental Biology*), Jutta Joormann (*Psychology*), Douglas Kankel (*Molecular, Cellular, and Developmental Biology*), Haig Keshishian (*Molecular, Cellular, and Developmental Biology*), †John Krystal (*School of Medicine, Psychology*), Rajit Manohar (*Electrical Engineering*), †Linda Mayes (*School of Medicine, Psychology*), Greg McCarthy (*Psychology*), Wendy Mendes (*Psychology*), Kia Nobre (*Psychology*), Laurie Santos (*Psychology*), †Dana Small (*School of Medicine, Psychology*), †Jane Taylor (*School of Medicine, Psychology*), Nick Turk-Browne (*Psychology*)

**Associate Professors** †Alan Anticevic (*School of Medicine, Psychology*), Arielle Baskin-Sommers (*Psychology*), Abhishek Bhattacharjee (*Computer Science*), †Sreenganga Chandra (*School of Medicine, Molecular, Cellular, and Developmental Biology*), Steve Chang (*Psychology*), †Philip Corlett (*School of Medicine, Psychology*), Dylan Gee (*Psychology*), Smita Krishnaswamy (*Genetics*), †Ifat Levy (*School of Medicine, Psychology*), †James McPartland (*School of Medicine, Psychology*), Weimin Zhong (*Molecular, Cellular, and Developmental Biology*)

**Assistant Professors** Maria Gendron (*Psychology*), Julia Leonard (*Psychology*), Samuel McDougale (*Psychology*), Michael O'Donnell (*Molecular, Cellular, and Developmental Biology*), Priya Panda (*Electrical Engineering*), Robb Rutledge (*Psychology*), Ilker Yildirim (*Psychology*)

**Lecturer** Stephanie Lazzaro (*Psychology*)

†A joint appointment with a primary affiliation in another department or school.

See visual roadmap of the requirements.

View Courses

## Courses

**NSCI 141a / PSYC 141a, The Criminal Mind** Arielle Baskin-Sommers

Theoretical and empirical study of the development of criminal behavior, including constitutional, social, and neurobiological elements. Personality and psychopathological factors associated with criminal behavior; theoretical and psychobiological explanations

of crime; the biological/environment interaction; the impact of psychobiological models for policy and intervention. SO

**NSCI 160a / PSYC 160a, The Human Brain** Gregory McCarthy

Introduction to the neural bases of human psychological function, including social, cognitive, and affective processing. Preparation for more advanced courses in cognitive and social neuroscience. Topics include memory, reward processing, neuroeconomics, individual differences, emotion, social inferences, and clinical disorders. Neuroanatomy, neurophysiology, and neuropharmacology are also introduced. SC

**NSCI 320a / MCDB 320a, Neurobiology** Haig Keshishian and Paul Forscher

The excitability of the nerve cell membrane as a starting point for the study of molecular, cellular, and systems-level mechanisms underlying the generation and control of behavior. At least 1 semester of college chemistry is strongly recommended. SC o Course cr

**NSCI 321La / MCDB 321La, Laboratory for Neurobiology** Haig Keshishian

Introduction to the neurosciences. Projects include the study of neuronal excitability, sensory transduction, CNS function, synaptic physiology, and neuroanatomy. Concurrently with or after MCDB 320. SC ½ Course cr

**NSCI 324a / BENG 230a / MB&B 330a / MCDB 330a, Modeling Biological Systems I**

Thierry Emonet and Kathryn Miller-Jensen

Biological systems make sophisticated decisions at many levels. This course explores the molecular and computational underpinnings of how these decisions are made, with a focus on modeling static and dynamic processes in example biological systems. This course is aimed at biology students and teaches the analytic and computational methods needed to model genetic networks and protein signaling pathways. Students present and discuss original papers in class. They learn to model using MatLab in a series of in-class hackathons that illustrate the biological examples discussed in the lectures. Biological systems and processes that are modeled include: (i) gene expression, including the kinetics of RNA and protein synthesis and degradation; (ii) activators and repressors; (iii) the lysogeny/lysis switch of lambda phage; (iv) network motifs and how they shape response dynamics; (v) cell signaling, MAP kinase networks and cell fate decisions; and (vi) noise in gene expression. Prerequisites: MATH 115 or 116. BIOL 101-104, or with permission of instructors. This course also benefits students who have taken more advanced biology courses (e.g. MCDB 200, MCDB 310, MB&B 300/301). QR, SC o Course cr

**NSCI 325b / BENG 465b / MB&B 361b / MCDB 361b, Modeling Biological Systems II**

Thierry Emonet

Advanced topics related to dynamical processes in biological systems. Processes by which cells compute, count, tell time, oscillate, and generate spatial patterns. Time-dependent dynamics in regulatory, signal-transduction, and neuronal networks; fluctuations, growth, and form. Comparisons between models and experimental data. Dynamical models applied to neurons, neural systems, and cellular biophysical processes. Use of MATLAB to create models. Prerequisite: MCDB 330 or equivalent, or a 200-level biology course, or with permission of instructor. QR

**NSCI 329a / MCDB 329a, Sensory Neuroscience Through Illusions** Damon Clark and Michael O'Donnell

Animals use sensory systems to obtain and process information about the environment around them. Sensory illusions occur when our sensory systems provide us with surprising or unexpected percepts of the world. The goal of this course is to introduce students to sensory neuroscience at the levels of sensor physiology and of the neural circuits that process information from sensors. The course is centered around sensory illusions, which are special cases of sensory processing that can be especially illustrative, as well as delightful. These special cases are used to learn about the general principles that organize sensation across modalities and species. Prerequisites: BIOL 101-104; NSCI 160 or NSCI 320 or permission of instructor. SC

**\* NSCI 444a / PSYC 442a, Topics in Clinical Neuroscience** Tyrone Cannon

This course is an advanced seminar examining the biological bases of psychopathology. We cover research, theory, and controversies regarding the roles of genetics, neurotransmitter systems, brain development and function, and other biological influences in the major classes of mental disorders, including anxiety disorders, depression, schizophrenia, bipolar disorder, obsessive compulsive disorder, substance use disorders, eating disorders, and autism. Prominent theories emanating from cognitive, behavioral, and interpersonal approaches to psychopathology are examined in the context of multilevel models of behavior, and the interplay of biological and psychological factors are a central theme throughout. Prerequisite: PSYC 160 SO

**[ NSCI 445, Systems Neuroscience ]**

**\* NSCI 449a / PSYC 449a, Neuroscience of Social Interaction** Steve Chang

This seminar covers influential studies that inform how the brain enables complex social interactions from the perspectives of neural mechanisms. Students thoroughly read selected original research papers in the field of social neuroscience across several animal species and multiple modern neuroscience methodologies. In class, the instructor and students work together to discuss these studies in depth. Focused topics include neural mechanisms behind brain-to-brain coupling, empathy, prosocial decision-making, oxytocin effects, and social dysfunction. Prerequisite: PSYC 160 or permission from the instructor. SC

**\* NSCI 470a, Independent Research** Damon Clark and Steve Chang

Research project under faculty supervision taken Pass/Fail; does not count toward the major, but does count toward graduation requirements. Students are expected to spend approximately ten hours per week in the laboratory. A final research report and/or presentation is required by end of term. Students who take this course more than once must reapply each term. To register, students must submit a form and written plan of study with bibliography, approved by the faculty research adviser and DUS, by the end of the first week of class. More detailed guidelines and forms can be obtained from <http://neuroscience.yale.edu>.

**\* NSCI 480a, Senior Non-empirical Research** Damon Clark and Steve Chang

Research survey under faculty supervision fulfills the senior requirement for the B.A. degree and awards a letter grade. For NSCI seniors only (and second term juniors with DUS permission). Students are expected to conduct a literature review, to complete written assignments, and to present their research once in either the fall or spring term. Students are encouraged to pursue the same research project for two terms.

The final research paper is due in the hands of the sponsoring faculty member, with a copy submitted to the department, by the stated deadline near the end of the term. To register, students submit a form and written plan of study with bibliography, approved by the faculty research adviser and DUS, by the end of the first week of classes. More detailed guidelines and forms can be obtained from <http://neuroscience.yale.edu>.

**\* NSCI 490a, Senior Empirical Research** Damon Clark and Steve Chang  
Laboratory or independent empirical research project under faculty supervision to fulfill the senior requirement for the B.S. degree. For NSCI seniors only (and second term juniors with DUS permission); this course awards a letter grade. Students are expected to spend at least ten hours per week in the laboratory, to complete written assignments, and to present their research once in either the fall or the spring term. Written assignments include a short research proposal summary due at the beginning of the term and a full research report due at the end of the term. Students are encouraged to pursue the same research project for two terms, in which case, the first term research report and the second term proposal summary may be combined into a full research proposal due at the end of the first term. Final papers are due by the stated deadline. Students should reserve a research laboratory during the term preceding the research. To register, students must submit a form and written plan of study with bibliography, approved by the faculty research adviser and DUS, by the end of the first week of classes. More detailed guidelines and forms can be obtained from <http://neuroscience.yale.edu>.