

NEUROSCIENCE

Directors of undergraduate studies: Damon Clark (MCDB), KBT 224 and Nicholas Turk-Browne (Psychology), SSS 305; neuroscience.dus@yale.edu; 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 molecules to minds. At one end, molecular and cellular 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 neurology 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 S&DS 103, 105, 262, or PSYC 200.

PLACEMENT PROCEDURES

Students must apply to enter the major. Applications are reviewed at the end of each term; decisions are based on a cover letter, transcript, completed Neuroscience major worksheet, and optional resume. More information regarding the application process is available on the program's website.

REQUIREMENTS OF THE MAJOR

Both the B.S. and B.A. Neuroscience degrees require a minimum of 18.5 credits, including the three prerequisites, 15 lecture or seminar courses, and one laboratory, as follows:

1. Two neuroscience foundation courses, NSCI 160 and NSCI 320.
2. One neuroscience lab chosen from NSCI 321L, 235, 240, 260, 265 (ANTH 148L), NSCI 558.
3. Eleven electives from the following core groupings, with a minimum of two from the Systems/Circuits/Behavior Core, two from the Molecular/Cellular/Biological Core, one from the Quantitative Core, one from the Basic Allied Core, and one from the Advanced Allied Core (or a second course from the Quantitative Core). No more than two credits may be taken from the Other Allied Core.

Systems/Circuits/Behavior Core: NSCI 340, 341, 346, 352, 355, 360, 442, 445

Molecular/Cellular/Biological Core: NSCI 324; NSCI 325; NSCI 420; MB&B 300 or MCDB 300; MCDB 200; MCDB 202; MCDB 205; MCDB 210; MCDB 310; MCDB 370; MCDB 450; MCDB 452

Quantitative Core: MATH 116 (recommended) or 112, 115, 120; MATH 222, 225, or MATH 230, 231; MATH 244; MATH 246 or 247; AMTH 262; NSCI 324 or 325; CPSC 202; PHYS 301

Basic Allied Core: PHYS 170, 180, 200, or 260; PHYS 171, 181, 201, or 261; CHEM 161 or 163; CHEM 165 or 167; CHEM 174 or 220; CHEM 175 or 221

Advanced Allied Core: BENG 350; BENG 444 or 485; CPSC 100 or 112; 201, 202, 223, 323, 365, 475 or 476; EENG 200; PHYS 420; S&DS 361

Other Allied Core: NSCI 141, 147, 161; CGSC 110

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. More information about the senior requirements of the B.A. and B.S. degree is available on the department website. 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.A. degree program The B.A. degree requires two course credits in non-empirical research, NSCI 480 and 481; or one credit in non-empirical research, NSCI 480 or NSCI 481, and one credit in empirical research, NSCI 490 or 491. These courses are only open to Neuroscience seniors and they award a letter grade. Under faculty supervision, students are required to conduct a literature review, complete written assignments, and make a presentation. The final research paper is due to the sponsoring faculty member, with a copy submitted to the department, by the stated deadline near the end of the term. Seniors are also required to present their research once in either the fall or the spring term. To register, students must submit a form, and a 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 the department website.

B.S. degree program The B.S. degree requires two course credits of empirical research, NSCI 490 and 491. These courses are only available to Neuroscience seniors (and second term juniors with DUS permission), and they award a letter grade. Students are expected

to spend at least ten hours per week in the laboratory, to complete written assignments, and to make a presentation. Research can be conducted over original, archival, or consortium data sets. 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 full 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 near the end of the term. Seniors are also required to present their research once in either the fall or the spring term. Students should line up 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 a 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 the department website.

ADVISING

Departmental advisers Schedules for all majors must be discussed with, and approved by, one of the directors of undergraduate studies. Only then may a schedule be submitted to the residential college dean's office. For questions concerning credits for courses taken at other institutions, or courses not listed in this bulletin, students should consult with one of the directors of undergraduate studies.

REQUIREMENTS OF THE MAJOR

Prerequisites BIOL 101, 102, 103, 104; and one of S&DS 103, 105, 262, or PSYC 200

Number of courses 18.5 courses (incl prereqs and senior req)

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

Distribution of courses *B.A.* or *B.S.* – 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 basic allied core course, 1 adv allied core course, and more than 2 other allied core courses

Senior requirement *B.A.* – 2 courses in non-empirical research; or 1 course in empirical research and 1 course in non-empirical research; *B.S.* – 2 courses in empirical research

FACULTY OF THE NEUROSCIENCE MAJOR

Professors †Amy Arnsten (*School of Medicine, Psychology*), Tom Brown (*Psychology*), Ty Cannon (*Psychology*), John Carlson (*Molecular, Cellular, and Developmental Biology*), BJ Casey (*Psychology*), Marvin Chun (*Psychology*), Paul Forscher (*Molecular, Cellular, and Developmental Biology*), Jutta Joorman (*Psychology*), Douglas Kankel (*Molecular, Cellular, and Developmental Biology*), Haig Keshishian (*Molecular, Cellular, and Developmental Biology*), †Daeyeol Lee (*School of Medicine, Psychology*), †Linda Mayes (*School of Medicine, Psychology*), Greg McCarthy (*Psychology*), Laurie Santos (*Psychology*), Jane Taylor (*School of Medicine, Psychology*), Nick Turk-Browne (*Psychology*), Robert Wyman (*Molecular, Cellular, and Developmental Biology*)

Associate Professors †Sreenganga Chandra (*School of Medicine, Molecular, Cellular, and Developmental Biology*), Thierry Emonet (*Molecular, Cellular, and Developmental Biology*), Weimin Zhong (*Molecular, Cellular, and Developmental Biology*)

Assistant Professors Arielle Baskin-Sommers (*Psychology*), Steve Chang (*Psychology*), Damon Clark (*Molecular, Cellular, and Developmental Biology*), Molly Crockett (*Psychology*), Dylan Gee (*Psychology*), Avram Holmes (*Psychology*), †Hedy Kober (*School of Medicine, Psychology*), †Ifat Levy (*School of Medicine, Psychology*)

Lecturer Nelson Donegan (*Psychology*)

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

Courses

NSCI 147a / PSYC 147a, Animal Models of Clinical Disorders Nelson Donegan

An interdisciplinary approach to understanding and treating psychiatric disorders, integrating clinical psychology, psychiatry, and advances in basic neuroscience. Focus on how research with animal models can advance our understanding of psychiatric disorders and generate more effective treatments for patients. Topics include drug addiction, depression, Parkinson's disease, and schizophrenia. SC, 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 235a or b / PSYC 270a or b, Research Methods in Behavioral Neuroscience Nelson Donegan

Students design and conduct research to study brain function and behavior. Emphasis on hands-on participation in behavioral and neuroscience techniques. Prerequisites: PSYC 160 or 170, and a course in statistics, or with permission of instructor. SC

NSCI 240b / PSYC 230b, Research Methods in Human Neuroscience Gregory McCarthy

Experience in methods of human neuroscience research. Focus on functional magnetic resonance imaging, electroencephalography, and evoked potentials. Some attention to psychophysiological techniques such as the measurement of skin conductance. Students design experiments, acquire data, and perform analyses. Extensive use of MATLAB. Prerequisites: PSYC 110, 170, and a course in statistics, or permission of instructor. SC

*** NSCI 258b / PSYC 258b, Computational Methods in Human Neuroscience** Nicholas Turk-Browne

This course provides training on how to use computational science for the advanced analysis of brain imaging data, primarily from functional magnetic resonance imaging (fMRI). Topics include scientific programming, high-performance computing, machine learning, network/graph analysis, real-time neurofeedback, nonparametric statistics, and functional alignment. Prerequisites: CPSC 100 or upper level course involving programming (CPSC 201, CPSC 202, and knowledge of Python preferred); PSYC 160; PSYC 230 preferred. QR, SC

NSCI 265a / ANTH 148La / PSYC 248a, Hormones and Behavior Claudia Valeggia and Eduardo Fernandez-Duque

Introductory laboratory focusing on the interaction between hormones and behavior from an evolutionary and developmental perspective. Students gain competency in basic laboratory techniques (pipetting, diluting, aliquotting, etc.) and develop a small, group research project. Additional study of the theoretical background on which any laboratory work is developed through reading and discussing primary scientific literature on both human and non-human primates. SC ½ Course cr

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. Prerequisites: year of college-level chemistry; a course in physics is strongly recommended. SC

NSCI 321La / MCDB 321La, Laboratory for Neurobiology Haig Keshishian, Robert Wyman, and Fernando Vonhoff

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 / MB&B 330a / MCDB 330a, Introduction to Dynamical Systems in Biology Thierry Emonet and Kathryn Miller-Jensen

Study of the analytic and computational skills needed to model genetic networks and protein signaling pathways. Review of basic biochemical concepts including chemical reactions, ligand binding to receptors, cooperativity, and Michaelis-Menten enzyme kinetics. Deep exploration of biological systems including: kinetics of RNA and protein synthesis and degradation; transcription activators and repressors; lysogeny/lysis switch of lambda phage and the roles of cooperativity and feedback; network motifs such as feed-forward networks and how they shape response dynamics; cell signaling, MAP kinase networks and cell fate decisions; bacterial chemotaxis; and noise in gene expression and phenotypic variability. Students learn to model using MatLab in a series of in-class hackathons that illustrate biological examples discussed in lectures. Prerequisites: BIOL 101 and 102, and PHYS 170 and 171 or equivalents, or with permission of instructors. QR, SC

NSCI 325b / BENG 465b / MB&B 361b / MCDB 361b, Dynamical Systems in Biology Damon Clark, Thierry Emonet, and Jonathon Howard

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 340a / PSYC 335a, Cognitive Neuroscience Staff

Examination of the fundamental and advanced principles underlying several cognitive functions from the perspectives of modern cognitive, systems, and computational neuroscience. Discussion of cognition in both humans and animal models through research of general neurobiological principles followed by several key examples from research studies that have influentially shaped the field. Prerequisite: PSYC 160 or specific chapter readings from the instructor. SC

NSCI 341a / PSYC 376a, Learning and Memory Thomas Brown

The basic facts, general principles, and theories that describe how higher animals, from mice to humans, are changed by their experiences. The historically separate fields of learning and memory research desegregated under a neuroscientific perspective that recognizes the evolutionary continuity among higher animals. Prerequisite: Introductory courses in biology and psychology, or permission of instructor. SC, SO

NSCI 346b / PSYC 321b, Psychopharmacology Thomas Brown

Study of therapeutic and recreational drugs that affect the central nervous system and influence mood, cognition, perception, and behavior. Drugs considered vary from psychotropic to hypnotic to narcotic. Prerequisite: PSYC 160 or 170 or equivalent, or permission of instructor. SC

NSCI 352b / CGSC 352b / PSYC 352b, Arrested or Adaptive Development in the Adolescent Brain BJ Casey

Study of empirical and theoretical accounts of adolescent-specific changes in the brain and in behavior that relate to the development of self control. Discussions will focus on adaptive and arrested adolescent brain development in the context of relevant legal, social, and health policy issues. SC

NSCI 355b / PSYC 303b, Social Neuroscience Molly Crockett

Exploration of the psychological and neural mechanisms that enable the formation, maintenance, and dissolution of social relationships. Topics include the neuroscience of how we form impressions and decide whether to instigate relationships with others; how we build relationships through trust, cooperation, attachment, conflict, and reconciliation; and group-level processes including intergroup bias, moral judgment, and decision making. Prerequisite: PSYC 110 or permission of instructor. SC

*** NSCI 442a / PSYC 428a, Neuroscience of Decision-Making** Molly Crockett

An overview and examination of the neuroscience of decision making. Interdisciplinary course highlighting research from cognitive neuroscience, psychology, behavioral economics, finance, marketing, computer science, and public health. Topics include utility and value, reinforcement learning, risky decision making, impulsivity and self control, social decision making, psychopathology, and commercial applications (e.g., neuromarketing and neurofinance). Permission of the instructor. SC

*** NSCI 470a and NSCI 471b, Independent Research** Damon Clark and Nicholas Turk-Browne

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 and NSCI 481b, Senior Non-empirical Research** Damon Clark and Nicholas Turk-Browne

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 and NSCI 491b, Senior Empirical Research** Damon Clark and Nicholas Turk-Browne

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>.