

NEUROSCIENCE

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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 (4 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 229L, 240, 258, 260, 270, 321L; PSYC 238.
3. Eleven electives from the following core groupings, with a minimum of: 2 from the Systems/Circuits/Behavior Core, 2 from the Molecular/Cellular/Biological Core, 1 from the Quantitative Core, 1 from the Computational Core, and 1 from the Basic Allied Core. No more than 2 credits may be taken from the Other Allied Core. Students may search—with the attributes indicated in each core grouping—for approved courses in YCS.

Systems/Circuits/Behavior Core (YC NSCI: Systems/Circuit/Behav): NSCI 340, 341, 346, 352, 355, 360, 440, 441, 442, 443, 445, 449, 479

Molecular/Cellular/Biological Core (YC NSCI: Molecular/Cell/Biol): NSCI 324, 325, 329, 420; MCDB 200, 202, 205, 210, 300, 310, 370, 450, 452; MB&B 300

Quantitative Core (YC NSCI: Quantitative): MATH 112, 115, 116, 120, 222, 225, 226, 230, 231, 244, 246, 247, 255, 256; ENAS 151; NSCI 324, 325; CPSC 202

Computational Core (YC NSCI: Computational): CPSC 100, 112, 201, 223, 323, 365, 452, 470, 475, 476; ENAS 130; PHYS 378; S&DS 123, 262, 361; NSCI 453

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

Other Allied Core (YC NSCI: Other Allied): NSCI 141, 161, 419, 455; BENG 485; MCDB 250; CGSC 110; PSYC 110; one additional Neuroscience lab course from the list above

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, to hear guest speakers and to discuss senior work progress with their peers and the directors of undergraduate studies (DUSes). 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 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 contribution 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 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 is 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.

ADVISING

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

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*), B. J. Casey (*Psychology*), Marvin Chun (*Psychology*), 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*), Laurie Santos (*Psychology*), †Dana Small (*School of Medicine, Psychology*), †Jane Taylor (*School of Medicine, Psychology*), Nick Turk-Browne (*Psychology*), Robert Wyman (*Molecular, Cellular, and Developmental Biology*)

Associate Professors †Alan Anticevic (*School of Medicine, Psychology*), Arielle Baskin-Sommers (*Psychology*), Abhishek Bhattacharjee (*Computer Science*), †Sreeganga Chandra (*School of Medicine, Molecular, Cellular, and Developmental Biology*), Steve Chang (*Psychology*), Damon Clark (*Molecular, Cellular, and Developmental Biology*), †Philip Corlett (*School of Medicine, Psychology*), Molly Crockett (*Psychology*), Thierry Emonet (*Molecular, Cellular, and Developmental Biology*), Avram Holmes (*Psychology*), †Hedy Kober (*School of Medicine, 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 Dylan Gee (*Psychology*), Maria Gendron (*Psychology*), Julia Leonard (*Psychology*), Samuel McDougale (*Psychology*), †John Murray (*School of Medicine, Physics*), 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 primary affiliation in another department or school.

See visual roadmap of the requirements.

View Courses

Courses

NSCI 160a / PSYC 160a, The Human Brain Robb Rutledge

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 240a / PSYC 230a, Research Methods in Human Neuroscience** Gregory McCarthy

Primary focus on structural, functional, and diffusion magnetic resonance imaging, with a secondary emphasis upon brain stimulation, electroencephalography, and evoked potentials. Students learn the fundamentals of each method and the experimental designs for which they are most applicable. Prerequisites: PSYC 160/NSCI 160 and a course in statistics, or permission of instructor. SC

* **NSCI 260a / PSYC 260a, Research Methods in Psychopathology: Psychotic Disorders** Tyrone Cannon

Methods of research in psychopathology. Focus on longitudinal designs, high-risk sampling approaches, prediction of outcomes, and modeling change over time. Students design and perform analyses of clinical, cognitive, genetic, neuroimaging and other kinds of measures as predictors of psychosis and related outcomes, using existing datasets supplied by the instructor. SO

* **NSCI 280a / S&DS 280a, Neural Data Analysis** Ethan Meyers

We discuss data analysis methods that are used in the neuroscience community. Methods include classical descriptive and inferential statistics, point process models, mutual information measures, machine learning (neural decoding) analyses, dimensionality reduction methods, and representational similarity analyses. Each week we read a research paper that uses one of these methods, and we replicate these analyses using the R or Python programming language. Emphasis is on analyzing neural spiking data, although we also discuss other imaging modalities such as magneto/electro-encephalography (EEG/MEG), two-photon imaging, and possibility functional magnetic resonance imaging data (fMRI). Data we analyze includes smaller datasets, such as single neuron recordings from songbird vocal motor system, as well as larger data sets, such as the Allen Brain observatory's simultaneous recordings from the mouse visual system. Prerequisite: S&DS 230. Background in neuroscience is recommended but not required (e.g., it would be useful to have taken at the level of NSCI 160).

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

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 0 Course cr

NSCI 325b / BENG 465b / MB&B 361b / MCDB 361b, Modeling Biological Systems II
Joe 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 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 340b / PSYC 335b, Cognitive Neuroscience Steve Chang

This course covers how cognition is made by the brain. Students learn brain mechanisms underlying human cognition, including making decisions, paying attention, regulating emotion, remembering events, as well as understanding others. The course discusses both established and newly emerging findings based on several landmark experiments in both humans and animals. During this process, students

are also introduced to cutting-edge techniques in cognitive neuroscience for studying human cognition. Prerequisite: PSYC 160 or specific chapter readings from the instructor. SC

NSCI 355a / PSYC 303a, Social Neuroscience Stephanie Lazzaro

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 361a / CGSC 274a / PSYC 261a, Algorithms of the Mind Ilker Yildirim

This course introduces computational theories of psychological processes, with a pedagogical focus on perception and high-level cognition. Each week students learn about new computational methods grounded in neurocognitive phenomena. Lectures introduce these topics conceptually; lab sections provide hands-on instruction with programming assignments and review of mathematical concepts. Lectures cover a range of computational methods sampling across the fields of computational statistics, artificial intelligence and machine learning, including probabilistic programming, neural networks, and differentiable programming. Students must have a programming background, ideally in a high-level programming language such as Python, Julia or Matlab. Students must also have college-level calculus. The course will substantially use Julia and Python. QR, SC, SO o Course cr

*** NSCI 443b / PSYC 443b, Topics in the Neuroscience of Memory** Stephanie Lazzaro

A seminar style overview and examination of the neuroscience of memory. In this seminar, we discuss some significant historical findings in the study of memory, as well as focus on more recent, current research. How memory works and how memories can be altered and improved are discussed. Topics may include sleep and memory consolidation, re-consolidation, false memories, superior autobiographical memory, as well as the effects of rewards, novelty, exercise, and social cues on various types of memory. Goals for this course include acquiring an in-depth and integrative understanding of the current research and directions surrounding the neuroscience of memory, and thinking critically about the methodology and evidence in the research papers that are read and discussed. We discuss strengths and limitations of the research and theories, as well as real-world applications. Prerequisites: PSYC 110, PSYC 160, or PSYC 130

[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 455b / PSYC 432b, Under Pressure: The Psychology of Stress** Dylan Gee

While stress serves an adaptive function that is critical for survival, chronic or extreme stress can have a negative impact on mental and physical health. Understanding the broad range of factors that can exacerbate or reduce stress, how we respond to stress, and the ways that experiences and effects of stress can differ across people and across stages of development can provide foundational insights for dealing with stress in our lives. This seminar integrates psychological, neurobiological, social, developmental, and clinical perspectives on stress. In addition to developing a foundation in the theoretical and empirical literature on stress, students will have the opportunity to engage in experiential learning related to coping skills drawn from evidence-based interventions in psychology. Priority given to seniors. Prerequisites: There are no formal prerequisites for the course, but one of the following is strongly recommended: PSYC 110, PSYC 160, PSYC 230, PSYC 335, PSYC 352, or PSYC 376. so

* **NSCI 470a and NSCI 471b, 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 479b / PSYC 479b, Computational Basis of Seeing and Thinking** Ilker Yildirim

The goal of this seminar is to discuss the computational basis of seeing and thinking in the mind and brain. We are especially concerned with this question of how perception gets us to cognition: How is it that perception transforms raw, unprocessed, unorganized, incoming sensory signals arising from our physical environments – for example, the light that bounces off surfaces and arrives at your retina, raw audio waves hitting your ears, or the vibro-tactile sensations you feel at your fingertips when you touch a surface – into things like objects and people, into things that we can think about? We somewhat prioritize the field of scene perception, where many fundamental questions about the nature of seeing and aspects of cognition arise prominently, and much of those questions remain open to this date. We draw upon readings and classroom discussions to find out where the literature stands, including behavioral, neural, and computational studies, all in the context of searching for a mechanistic, functional account of how the brain produces percepts and thoughts about objects, scenes, and people. so

* **NSCI 480a and NSCI 481b, 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 and NSCI 491b, 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>.