NEUROSCIENCE

Directors of undergraduate studies: Damon Clark (neuroscience.dus@yale.edu) (MCDB), YSB C148; Nicholas Turk-Browne (neuroscience.dus@yale.edu) (Psychology), SSS 305; 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
To join the major, students should submit a transcript and a completed Neuroscience major worksheet to the department registrar. (neuroscience.registrar@yale.edu)

REQUIREMENTS OF THE MAJOR
A minimum of 18.5 credits is required, including the three prerequisites, 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 chosen from NSCI 229L, 258, 260, 270, 321L.

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 Computational Core, and one from the Basic Allied 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, 440, 441, 442, 445; PSYC 238, PSYC 449
   Molecular/Cellular/Biological Core: NSCI 324, 325, 420; MCDB 200, 202, 205, 210, 300, 310, 370, 450, 452; MB&B 300
   Quantitative Core: MATH 112, 115, 116, 120, 222, 225, 226, 230, 231, 244, 246, 247 MATH 255, MATH 256; ENAS 151; NSCI 324, 325; CPSC 202
   Computational Core: CPSC 100, 112, 201, 223, 323, 326, 470, 475, 476; ENAS 130; S&DS 123, 262, S&DS 355, 361; NSCI 453
   Basic Allied Core: PHYS 170, 171, 180, 181, 200, 201, 260, 261; CHEM 161, 163, 165, 167, 174, 175, 220, 221
   Other Allied Core: NSCI 141, 161, 240, 419, 455, 479; 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.

Roadmap See visual roadmap of the requirements.

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 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.

ADVISING
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 this bulletin, students should contact the Neuroscience registrar.

REQUIREMENTS OF THE MAJOR
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)

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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 Kobes (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)

†Program advisers
**Courses**

**NSCI 160b / PSYC 160b, 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 161b / PSYC 161b, Drugs, Brain, and Behavior**  
Hedy Kober  
An introduction to psychoactive drugs and their effects on both brain and behavior. Review of pharmacological and brain mechanisms of different classes of legal, illegal, and medicinal drugs, including alcohol, caffeine, tobacco, stimulants, depressants, antidepressants, and hallucinogens. Individual drugs’ pharmacokinetics, mechanisms of action, dosing, routes of administration, and patterns and effects of use and misuse. Some attention to substance use disorders/addictions, prevention, and treatment. sc

* **NSCI 258b / PSYC 258b, Computational Methods in Human Neuroscience**  
Nick 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, CPSC 112 or other course involving terminal commands and programming (Python preferred); course in statistics and/or data science; PSYC 160 or other human neuroscience course; or permission of instructor. QR, sc

* **NSCI 270a / PSYC 270a, Research Methods in Cognitive Neuroscience**  
Stephanie Lazzaro  
This course introduces methods used by cognitive neuroscientists to discover the structural and functional features of the nervous system. A combination of lectures and hands-on lab activities help students understand the structure and function of the human brain. WR, 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

**NSCI 321La / MCDB 321La, Laboratory for Neurobiology**  
Haig Keshishian and Paul Forscher  
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 324a / MB&B 330a / MCDB 330a, Modeling Biological Systems I**  
Thierry Emonet and Jing Yan  
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

**NSCI 325b / BENG 465b / MB&B 361b / MCDB 361b, Modeling Biological Systems II**  
Thierry Emonet, Joe Howard, and Damon Clark  
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 and Illusions**  
Damon Clark  
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 341b / PSYC 376b, Learning and Memory  Samuel McDougle
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 352a / CGSC 352a / PSYC 352a, Arrested or Adaptive Development of 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. Prerequisites: PSYC 110, PSYC 160.  sc

NSCI 360b / PSYC 316b, Clinical Neuroscience  Tyrone Cannon
The biological bases of psychopathology, with attention to the interplay of biological and psychological factors. Research and theory regarding the role of biological influences such as genetics, neuronal physiology and signaling, and psychopharmacology in the major classes of mental disorders. Discussion of mood and anxiety disorders, schizophrenia, addictions, personality disorders, eating disorders, and autism.  sc

* NSCI 419b / CGSC 419b / PSYC 419b, Topics in Brain Development, Law, and Policy  BJ Casey
Healthy development is a fundamental right of the individual, regardless of race, ethnicity, socioeconomic status, or gender. Youth require special protections of their rights due to vulnerabilities related to their physical and mental immaturity. These rights include, not only protections, but opportunities for building the cognitive, emotional, and social skills necessary for becoming a healthy adult and a contributing member of society. This seminar examines the extent to which legal policies and practices in the treatment of youths are consistent with scientific knowledge on psychological and brain development. Each class discusses one or more legal cases highlighted in the context of brain and psychological science and current laws and policies. Prerequisite: PSYC 110 and PSYC 160 preferred.  sc

* NSCI 440b / CGSC 420b / PSYC 420b, Topics in Clinical Neuroscience  Avram Holmes
An overview and examination of the neuroscience of psychiatric illness. We focus on cutting-edge research in humans and animals aimed at understanding the biological mechanisms that underlie psychiatric illness. Although these questions date back to early philosophical texts, only recently have experimental psychologists and neuroscientists begun to explore this vast and exciting domain of study. We discuss the evolutionary and developmental origins of individual differences in human personality, measurement issues, fundamental dimensions of psychopathology, stability/plasticity, heritability, and implications therapeutic interventions as well as the associated broader implications for public policy. A major focus is on the neurobiology of fear and anxiety, including brain circuits, molecular genetic pathways, and epigenetics. A secondary focus is on differences in behavior and biology that confer risk for the development of depression and addiction, including the biological systems involved in hedonic pleasure, motivated goal pursuit, and the regulation of impulses in the face of everyday temptation. Students should have some background in psychology; PSYC 110 and PSYC 160 preferred.  sc

* NSCI 441a / PSYC 438a, Computational Models of Human Behavior  Robb Rutledge
Why do we do the things we do? How do we adapt to changes in the environment? And how does our happiness depend on our choices and what happens to us? How can computational models help us to gain new insights into psychological processes? The goal of this course is to use computational models to understand human behavior and its relationship to our emotions. Data is collected in a variety of tasks including new experiments designed by students, and is analyzed using computational models. CPSC 112 or other course involving programming (e.g., C++, Java, Python, Matlab), 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 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 453a / CPSC 453a, Unsupervised Learning for Big Data  Smita Krishnaswamy
This course focuses on machine-learning methods well-suited to tackling problems associated with analyzing high-dimensional, high-throughput noisy data including: manifold learning, graph signal processing, nonlinear dimensionality reduction, clustering and information theory. Though the class goes over some biomedical applications, such methods can be applied in any field. Prerequisite: Knowledge of linear algebra and Python Programming.

* NSCI 455b / PSYC 432b, Under Pressure: The Psychology of Stress  Dylan Gee
Stress is pervasive in everyday life. Why do humans experience stress, and what causes stress in today’s society? How does stress affect the ways we think, feel, and behave? Why are some people particularly susceptible to the effects of stress on mental and physical health? What factors can buffer against the consequences of stress, and how can we leverage stress management techniques to effectively cope with stress? This course draws from psychological, neurobiological, social, developmental, and clinical perspectives to address these questions. In addition to an in-depth study of theory, research, and intervention in the field of stress, this seminar is designed to translate scientific advances to help students learn how to more effectively manage stress in their own lives. Priority given to juniors and 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, Independent Research  Nick Turk-Browne and Damon Clark
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 479a / PSYC 479a, 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, Senior Non-empirical Research  Nick Turk-Browne and Damon Clark
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  Nick Turk-Browne and Damon Clark
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.