Cognitive Neuroscience

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Suggested reading:

1. Gazzaniga, M. S., Ivry, R. B. & Mangun, G. R. (2009) *Cognitive Neuroscience: The biology of the mind* (3d ed.). New York: W.W.Norton. https://www.amazon.com/Cognitive-Neuroscience-Biology-Mind-4th/dp/0393913481
2. Banich M. T., & Compton, R. J. (2011) Cognitive Neuroscience (3d ed.). Wadsworth Publishing. http://www.amazon.com/Cognitive-Neuroscience-Marie-T-Banich/dp/0840032986/ref=sr_1_2?ie=UTF8&s=books&qid=1308212789&sr=1-2

Other readings relevant to the course:

3. Jessell T, Kandel E, Siegelbaum S, Schwartz J, Hudspeth A.J. (2012) Principles of Neural Science. Fifth Edition. McGraw-Hill
4. Squire L, Berg D, Bloom FE, du Lac S, Ghosh A, Spitzer NC (2012) Fundamental Neuroscience. 4th edition. Academic Press
5. Gazzaniga MS. (2009) The Cognitive Neurosciences. Fourth edition. The MIT Press
6. For browsing related articles in Scholarpedia: http://www.scholarpedia.org/article/Encyclopedia:Neuroscience

Overview

The core concept of this series of lectures is that cognitive neuroscience fundamentally means integrative brain research, which studies functional brain systems. What does functional brain systems mean, how it is constructed and function (interact) in the brain and what is their behavioral role is addressed. As the cerebral cortex is the most important brain region in understanding cognition, the major emphasis is given to this structure.

We begin with a short intro intro the (neuro)biological basis of brain structure and function. First I'll provide an overview about the structure and function of the neurons and glial cells, the elementary building blocks of the nervous system. Then we shortly go through the brain's functional (macroscopic) anatomy including the major regions and pathways. Supporting brain structures and functions such that circulation including the neurovascular coupling and mechanical protection will also be touched. Then the neurobiology and development of the cerebral cortex will be discussed from an organizational point of view. Overviewing the various methodological approaches of cognitive neuroscience will finish the first part of the course devoted to the biological basis.

The second part of the course will focus on the functional brain systems responsible for the major cognitive functions. We shortly overview the various methodological approaches of cognitive neuroscience, which is rooted in the diverse fields mentioned above. Beginning with sensory and perceptual systems we will have an insight into the organization of cortical functions as well as the elements of related cognitive processes. This section will help understand how functions are mapped or represented at the single cortical level as well as at the regional level including multiple cortical areas. The subsequent parts will review the cortical (and sub cortical) correlates of higher level, more abstract cognitive functions. Learning and memory will present an example of functions with multi-level organization from synaptic functions to brain systems. Language provides example for the dissociation of sub-functions, specifically understanding and production, and for understanding language as the interactions of the relevant cortical regions. Related to it is lateralization of functions at an even higher organizational level by the two hemispheres, which will be shortly discussed. Then we continue discussing active processes such that cognitive control and attention, which play major role in organizing behavior via complex brain circuits. This part will be closed by an introduction into the role of the cerebral cortex in controlling movement and more abstract functions such that intention.

The most important neurological problems related to the different cognitive functions will also be discussed. Some historical overview will be provided at the end of the course.

Additional references are provided in the notes window of some of the power point slides. Detailed program can be found below.

Topics addressed in each lecture

A. BACKGROUND
A.1. Neocortex. Evolution and development, circuits and dynamics.
A.2. Cognitive neuroscience: approaches.

B. FUNCTIONAL BRAIN SYSTEMS
B.1. Sensory and perceptual systems, sensory cortical maps
B.2. The neurobiology of high level perception: ventral-dorsal cortical dichotomies
B.3. Learning and memory. Dissecting the brain mechanisms.
B.4. Processing language
B.5. Hemispheric lateralization. Beyond language
B.6. Active vision and attention
B.7. Cognitive control. The prefrontal cortex (PFC).
B.8. Motor control of the cerebral cortex. From movements to intentions.

Schedule

Day 1

A. **BACKGROUND**

A.1. BIOLOGY OF COGNITION I: Neurons, neurotransmission and glia. Blood supply.

> **Neuron** doctrine. Neuronal diversity, cytoarchitectonics. Action potential: generation and transmission. Neuronal integration and signaling (coding).
> **Glia**: the not so silent majority of the CNS. Glial cell types and their functions.
> **Circulation**: Major arterial and venous system, the ventricles and the cerebrospinal fluid (liquor). Fine structure of the vascular system: the **neurovascular coupling**.
> **Mechanical protection** of the CNS: liquor, meninges and bones (skull, vertebrae).

A.2. BIOLOGY OF COGNITION II: Functional anatomy of the CNS. Organization of the cerebral cortex. Development and plasticity.

> A systemic overview of the macroscopic organization of the **central nervous system (CNS)**: structures (gray matter) and pathways (white matter). Topography, reciprocity, population dynamics (synfire chains, neuronal avalanches).
> **Cerebral cortex**: regions, areal designation, the *connectome*. Cortical networks: large-scale, micro and mesoscopic. Basics of cortical dynamics: synfire chains, neuronal avalanches.
> **Development** of the CNS: Ontogenesis. Cortical development: radial units, areal identification.

Day 2

A.3. COGNITIVE NEUROSCIENCE_INTRO. **Definition** (see also neuropsychology: http://en.wikipedia.org/wiki/Neuropsychology), **methodology** of cognitive neuroscience: psychology (behavior), neuroscience (biology), neurology (clinics), computation (model formalisms)

> **Psychological approach**: *psychophysics* (http://en.wikipedia.org/wiki/Psychophysics, http://en.wikipedia.org/wiki/Weber%E2%80%93Fechner_law), psychophysical metrics: reaction time, thresholds, learning curve, accuracy, double dissociation
> **Neurology, neuropsychology**: lesions (http://rad.usuhs.edu/rad/location/location_frame.html), disconnectivity, secondary degeneration, (epilepsy, neurodegenerative diseases, developmental diseases)
> **Neuroscience**: electrophysiology (single unit, multiunit, MEA, LFP), neuroanatomy (microscopic structure, tract tracing, neurogenetics), functional imaging (EEG, MEG, PET, fMRI)
> **[Modeling.** NOT TARGETED IN THIS COURSE; see at M Bányai**]**

B. **FUNCTIONAL BRAIN SYSTEMS**

B.1. SENSORY AND PERCEPTUAL SYSTEMS, SENSORY CORTICAL MAPS.

> Brain's sensory systems: vision (distant, photoreception) and touch (contact, mechanical). Perception is an **active** process. **Topography** (retinotopy, somatotopy). From **receptive fields** to **columns**: the grouping of neurons with similar stimulus

selectivity; receptive field properties. Visual and tactile **submodalities**, "labeled lines". Magno and parvocellular pathways (visual system). Cortical **functional representations**. Stages of processing, hierarchical cortical organization. Parallel, distributed processing: abundance of areas?

B.2. THE NEUROBIOLOGY OF HIGH LEVEL PERCEPTION: VENTRAL-DORSAL DICHOTOMIES ("what" and "where"/"how").

Ventral stream: perception for identification, **agnosias**. Temporal lobe: fusiform face area (grand mother cells), body area, sparse or population coding. Object invariance, holistic and detailed processing.

Dorsal stream: perception for action, some **ataxias**. Spatial processing: spatial relations, depth perception, motion perception. Parietal lobe: spatial frames of reference, sensory map transformations.

Other spatial functions: space and navigation. Egocentric, object centric and allocentric processing systems.

Day 3/4

B.3. LEARNING AND MEMORY. Neurology (H.M.), short overview of memories and responsible brain structures.

What is it in the brain?: **encoding**, **storage**, **retrieval**. Brain systems encoding **long term memories**: episodic information. Cellular level mechanism: **LTP**. Acquisition and storage: modality and domain specificity. **Working memory**: neural correlates, memory field. The role of sleep.

B4. PROCESSING OF LANGUAGE.

Comprehension: localization of the mental lexicon. **Processing**: localization of semantic, phonological and syntactic analyses. Bilingual representation. Neurobiology of **aphasias**. Right hemisphere's functions in language.

B.5. HEMISPHERIC LATERALIZATION. BEYOND LANGUAGE.

Grey and white matter **asymmetries**. Interhemispheric communication. Methods to study functional lateralizations. Hemispheric functions: the **spatial frequency** hypothesis.

Day 4

B.6. COGNITIVE CONTROL. THE PREFRONTAL CORTEX (PFC).

Phineas Gage, prefrontal tests. Prefrontal subdivisions: structural, functional. Neural basis of cognitive control: interactions within the PFC and with the caudal cortex; subcortical loops. The **coordinating** function of the PFC in brain; **bottleneck effects**. Further functions: neural basis of **cognitive emotional interactions** and social functioning; **decision making**.

B.7. ATTENTION.

How does perception become an **active process**? **Visual attention** as a case. Brain's **attentional networks:** neural systems for alerting, selecting and executing. **Eye movement** in focus: neurobiology. Units of attentional selection, **saliency maps** in the brain. **Biased competition**, neural mechanisms. Global attentional modulation, neural signatures of attention to features, objects, spatial attention. Source of the attentional

modulation: **top down vs. bottom up** processing. **Feature integration**: the role of attention in **binding**. Two stage model of vision, **neglect**, affected cortical areas.

B.8. MOTOR CONTROL.

The motor cortex: large scale organization; functional maps of the primary motor cortex. Movement coding, **brain-machine interface**. Efference copy. Motor learning, **mirror neurons**. Motor disorders.

REHEARSAL

A.4. **History** (emphasis on cortex).

- PP Broca (1824-1880): Broca area (Brodmann 44/45), Broca aphasia
- C Wernicke (1848-1905): Wernicke area (Brodman 22/40,41,42), Wernicke aphasia
- K Brodmann (1868–1918): cortical parcellation by cytoarchitecture, Brodmann areas
- SR Cajal (Nobel 1906): the father of modern neuroscience, identifying cell types and networks
- Lobotomy (leucotomy) (AE Moniz, Nobel 1949): psychosurgery, http://en.wikipedia.org/wiki/Lobotomy
- DO Hebb (1949): synaptic plasticity, Hebbian learning
- J O'Keefe & J Dostrovsky (1971): place cells
- T Lømo & T Bliss (1973): LTP
- V Mountcastel & D Hubel & T Wiesel (Nobel 1981): columnar organization, functional representations of the cerebral cortex
- R Sperry (Nobel 1981): split brain, hemispheric specializations
- P Rakic: cortex development and evolution, radial unit hypothesis
- J Kaas & M Merzenich (1983): (sensory) representational or map plasticity, evolution (Kaas)
- F Crick (Nobel for DNA 1962): neural correlates of consciousness
- G Edelman (Nobel for antibody 1972): neural Darwinism, reentrant loops
- M Abeles (1991): synfire chains, http://www.scholarpedia.org/article/Synfire_chains
- JM Beggs & D Plenz (2002): neuronal avalanche, http://www.scholarpedia.org/article/Neuronal_avalanche

Hungarians to note.

- R Bárány (Nobel 1914): vestibular apparatus
- K Schaffer (1864-1939): Schaffer collaterals of the hippocampus
- S Kuffler (1913-1980): receptive field in the retina, mentor of Hubel & Wiesel
- G Békésy (Nobel 1961): function of the cochlea
- J Selye (1907-1982): stress, General Adaptation Syndrome
- J Szentágothai (1912-1994): anatomical basis of columnar organization, cortical microcircuitry, mentor of P Somogyi
- E Grastyán (1924-1988): psychophysiology of the hippocampus, mentor of G Buzsáki

- G Buzsáki & P Somogyi & T Freund (The Brain Price 2011): structural and functional organization of the hippocampus

Day 5
Written exam