Cognitive Neuroscience

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Goal: the goal of the Cognitive Neuroscience module is twofold: 1) introducing the biological basis of brain structure and function and 2) overviewing the approaches of cognitive neuroscience and the functional brain systems responsible for our different cognitive abilities.

Topics addressed in each lecture

A. BACKGROUND
A.1. Neurobiology
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. Motor control of the cerebral cortex. From movements to intentions.
B.4. Learning and memory. Dissecting the brain mechanisms. Episodic and procedural memory.
B.5. Working and emotional memory
B.6. Executive functions of the prefrontal cortex
B.7. Active vision and attention
B.8. Processing language
B.9. Hemispheric lateralization. Beyond language
Addendum: Historical outlook

The detailed program and the schedule is given below.

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 about 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.

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 including psychophysics, clinics and neurobiology. 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 levels of the single neuron and the cortical area 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 comprehension 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 also includes an introduction into the role of the cerebral cortex in controlling movement and more abstract functions such that intention.

The most important brain diseases 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 given in the comment window of the power point presentations.

Schedule

Day 1

A. **BACKGROUND**

A.1. NUROBIOLOGY 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. NUROBIOLOGY II: Functional anatomy of the CNS. Organization of the cerebral cortex. Development, evolution and parcellation.

> A systemic overview of the macroscopic organization of the **central nervous system (CNS)**: structures (gray matter) and pathways (white matter). What is a brain?: evolutionary and developmental perspectives.
> **Cerebral cortex**: regions, areal designation, the *connectome*. Cortical networks: large-scale, micro and mesoscopic. Brain dynamics.
> **Development and evolution** of the cerebral cortex: radial units, areal identification, cortical expansion.

Day 2

A.3. COGNITIVE NEUROSCIENCE BASICS. **Definition** (see also neuropsychology), **methodology** of cognitive neuroscience: psychology (behavior), neuroscience (biology), neurology (clinics), computation (model formalisms)

> **Psychological approach**: *psychophysics*, psychophysical metrics: reaction time, thresholds, learning curve, accuracy, double dissociation
> **Neurology, neuropsychology**: lesions, 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 @ computational and theoretical modules**]**

B. **FUNCTIONAL BRAIN SYSTEMS**

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

> Brain's sensory systems: vision (distant, photoreception) and touch (contact, mechanical). **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. 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.

B4. 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. The role of sleep.

B.5. WORKING AND EMOTIONAL MEMORY. Active (dynamic) memories.

Working memory: delay response task and neuronal correlates, memory field and the prefrontal cortex. Working memory network. **Memory for emotion**: the orbitofrontal cortex and amygdala. Reversal learning and fear conditioning.

B.6. EXECUTIVE FUNCTIONS OF THE PREFRONTAL CORTEX

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**.

Day 4

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. PROCESSING LANGUAGE.

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

B.9. HEMISPHERIC LATERALIZATION. BEYOND LANGUAGE.

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

RECAP

Day 5

Written exam (test and essay)

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. Arbib MA, Érdi P, Szentágothai J (1997) Neural Organization: Structure, Function and Dynamics. MIT Press
7. For browsing related articles in Scholarpedia: http://www.scholarpedia.org/article/Encyclopedia:Neuroscience

ADDENDUM

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 (Nobel 2014 shared with the Mosers) & 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
- The Mosers (Nobel 2014 shared with O'Keefe): grid cells (2005), http://www.scholarpedia.org/article/Grid_cells,

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, fundamental contribution to many fields including the structure and function of the spinal cord, neuroendocrine system, cerebellum, thalamus, a founding person of the neuron doctrine (cf. continuity vs contiguity)
- 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