Neuroanatomy and Its impact on Structural and Functional Imaging (In Honor of Karl Zilles)

Nicola Palomero-Gallagher Co Organizer
Research Centre Julich
Julich, NRW
Germany

Hiromasa Takemura Co Organizer
Center for Information and Neural Networks (CiNet), NICT
吹田市, Osaka
Japan

Kevin Weiner, PhD Organizer
University of California, Berkeley
Berkeley, CA
United States

Educational Course - Half Day

Since its inception, OHBM has had an Educational Course during its annual meeting that educated researchers across the board - from students to PIs - about the importance of neuroanatomy and how different types of micro- and macroanatomical features of the brain impact structural and functional imaging. Notably, the past two years were the first years that an Educational Course focusing on the importance of neuroanatomy in human brain mapping was not offered. This does not indicate a lack of interest in neuroanatomy or a lack of new high-profile methods to quantify neuroanatomical features of the brain. In a modern age, it becomes even more important to understand neuroanatomy to accurately interpret neuroimaging data. For example, accurate anatomical knowledge on cortical areas and white matter tracts will improve accuracy of data-driven neuroimaging approaches including but not limited to cortical parcellation, functional connectivity, or tractography. Moreover, since multimodal, high-quality human neuroanatomy datasets have become publicly available in a computer-readable format, it is easier to incorporate neuroanatomical data into neuroimaging analysis. Therefore, the desired learning outcome for the audience would be to learn how to combine the strength of neuroanatomical and neuroimaging approaches to elucidate structure-function relationships in the human brain.

Objective

- Understand the organizational principles of the human brain on a macroscopic and microscopic level, with insights into changes that occur during development.
- Understand the advantages and limitations of neuroanatomical and neuroimaging techniques and methods for analysis of neuroimaging data incorporating anatomical information including cytoarchitectonics, receptor mapping, and white matter tracts.
- Understand study design and principles of analyses combining neuroanatomy and neuroimaging to address questions regarding structure-function relationships in the human brain.

Target Audience

The prime target audience is researchers with an interest in understanding the relationship between brain structure and function. This includes researchers with limited previous anatomical knowledge, but prior experience with neuroimaging.

Presentations

Neuroanatomy: The bridge between chaos and clarity in human brain mapping

As the first talk of the educational course, I will provide a general Introduction and roadmap to the course, as well as will discuss how and why neuroanatomy is critical for understanding how functional and anatomical features of the brain contribute to behaviour and cognition. Following the Introduction - and consistent with Karl's ability to balance the history of our field, as well as highlight how the most recent novel findings respectfully build on that foundation - I will review a series of recent findings showing that neuroanatomy serves as a bridge between chaos and clarity in human brain mapping. To do so, I will consider the classic dichotomy pitting primary vs. association cortices in which the former is considered to be much more orderly across spatial and functional scales compared to the latter. Nevertheless, in this educational course, students will learn that this classic dichotomy is actually not so clear. And instead, when considering largely overlooked anatomical structures that are largely hominoid-specific, the anatomical and functional organization of association cortices are much more orderly than a majority of classic and modern literature conveys. Thus, students have the rare opportunity to learn this information that (to our knowledge) is taught in less than a handful of universities throughout the world. For nearly all students, this may be the only opportunity to learn about these anatomical structures and their importance for understanding the relationship between brain structure and function in association cortices within the broad field of human brain mapping.

Presenter

Kevin Weiner, PhD, University of California, Berkeley Berkeley, CA, United States

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Julich Brain Atlas – Mapping to Discover

Starting from Brodmann's idea of structural-functional relationships at the level of cortical areas, extensive evidence has been provided that brain organization is based on multiple levels and that it is more differentiated than his cytoarchitectonic map suggests. Key in modern brain mapping is to consider novel preparations - such as neuroimaging and optical methods - to investigate intersubject variability as a basic principle of brain organization, and to integrate different data and maps into a spatial framework, or a human brain atlas. The large size of the human brain with its billions of nerve cells, forming complex networks, implies to collect and analyze large amounts of data, making high-performance computing mandatory. Deep learning has become a valuable tool to support brain mapping, and to derive new features describing its microstructure. Cytoarchitecture is a central element of brain organization, which allows to integrate other modalities such as connectivity, molecular, genetic or functional activity maps to a common ground, to investigate their manifold relationships and role for cognition and behaviour. Such an atlas, which I will describe in this talk, is being realized in the European Human Brain Project. It is offering an increasing number of high-quality and well-annotated datasets resulting from different experiments and from different labs worldwide. The Atlas provides a framework for localizing neuroimaging data, and for informing brain modelling and simulation. It is a tool to discover the brain.

Presenter

Katrin Amunts, Research Centre Juelich Juelich, Juelich, Germany

What Neurotransmitter Receptor Distribution Patterns Reveal About the Brain's Structural and Functional Organization

Neurotransmitters and their receptors constitute key molecules in signal transduction. Receptor binding sites are heterogeneously distributed throughout areas and layers of the cortical ribbon, and also within subcortical structures such as the amygdala or the thalamus. The balance between the densities of multiple receptor types in an architectonically defined brain region is represented by its "receptor fingerprint", and is crucial for the function of that particular brain region. Differences in the size and shape of receptor fingerprints segregate cortical types (primary sensory, motor, multimodal association) and hierarchical processing levels (primary and secondary sensory, association). Even within the level of primary cortices, areas of different sensory modalities can be differentiated by their receptor fingerprints. Here, the association between the cortical segregation as revealed by receptor distribution patterns and that identified with classical histological stainings (cyto- and myeloarchitecture) will be presented within the framework of the concept of "gradations" in cyto- and myeloarchitecture to explain the segregation of the cerebral cortex and the appearance of functional networks.

Presenter
Nicola Palomero-Gallagher, Research Centre Julich Julich, NRW, Germany

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White Matter Tract Analysis Using Neuroimaging and Neuroanatomy Datasets

In the late 19th century, a number of classical neuroanatomists emphasized the importance of white matter tracts to understand brain function. Recently, progress of diffusion MRI-based tractography has attracted resurgent interests in understanding the properties of white matter tracts in relation to brain function and disease. In the first part of this talk, I will provide a brief methodological overview of diffusion MRI-based tractography and discuss several studies using these methods to analyze white matter tracts in the human visual system, which are known to exist in anatomical studies. However, in common practice, tractography analyses require precise anatomical knowledge of white matter tracts in order to avoid false positives. Therefore, the analysis of unestablished structural connections using diffusion MRI-based tractography remains challenging. In the second part of this talk, I will discuss recent studies combining diffusion MRI with polarized light imaging, which provides micrometer-resolution neuroanatomical data of fiber orientations, to reveal the spatial organization of often overlooked white matter tracts. I will discuss how analyses combining neuroimaging and neuroanatomy data of white matter tracts show promise to improve our understanding of the functional organization of the human brain, as well as other species.

Presenter
Hiromasa Takemura, Center for Information and Neural Networks (CiNet), NICT 吹田市, Osaka, Japan

In-Vivo Histology, Myelin Imaging and Beyond: Challenges and advances in quantitative MRI

The main technique used for non-invasive mapping of the human brain is magnetic resonance imaging (MRI). Advances in the field have led to the development of quantitative MRI (qMRI). This technique provides biophysical parametric measurements that are useful in the investigation and diagnosis of the normal and abnormal brain. qMRI parameters have been shown to be sensitive to the microenvironment of brain tissue and are therefore named in vivo histology. Nevertheless, a major challenge in applying qMRI techniques is increasing their biological specificity. It is common to assume that qMRI parameters are sensitive to the myelin fraction, yet any brain tissue including myelin is a complex mixture of various molecules. Looking beyond myelin imaging, qMRI measurements display sensitivity to several microstructural properties such as lipid composition, iron content and cellular organization. Moreover, since water protons serve as the source of the MRI signal, the sensitivity of qMRI to different molecular microenvironments may be confounded by their sensitivity to the water content of the tissue. In my presentation, I will discuss the sensitivity and specificity of qMRI to different microstructural aspects. I will demonstrate how phantom experiments can be employed to address these issues. I will present novel qMRI approaches for disentangling different biological quantities. These approaches, which were validated against histological measurements, reveal the molecular composition of lipid samples and identify region-specific molecular signatures across the brain. Lastly, I will argue that the ability to disentangle molecular alterations from water-related changes opens the door to a more specific characterization of brain anatomy in-vivo.

Presenter
Aviv Mezer, PhD, The Hebrew University of Jerusalem Givat Ram, Jerusalem, Israel

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Neuroanatomy as a Window to the Developing Brain

How do micro- and macroanatomical features of the brain develop? Using the human visual system as a model system, I will discuss both theoretical and empirical findings regarding the macro- and microanatomical development of cortex during infancy and childhood. Specifically, I will describe recent advancements in quantitative MRI (qMRI) and diffusion MRI (dMRI) that provide exciting opportunities to measure in-vivo anatomical developments that are related to microstructural changes, which we validate with histological analyses in postmortem brain samples. Combining qMRI and dMRI, our results reveal profound tissue growth in infants as well as during childhood in functionally developing regions in high-level visual cortex. Comparing in-vivo measurements to histological measurements in postmortem samples suggests that cortical tissue growth is related to increased myelin and growth of neurofilaments (axons, dendritic arbors), but not to changes in cytoarchitecture. Finally, I will show that these microstructural changes are linked to functional developments and to developmental decreases in apparent cortical thickness, suggesting that cortex becomes more myelinated and not thinner during childhood development. I will end by discussing the implications of these results for understanding typical and atypical neuroanatomical development.

Presenter
Kalanit Grill-Spector, PhD, Stanford University Stanford, CA, United States