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All actions are governed by a continuous interplay between ex-afferent input through various sensory organs, followed by the generation of efferent commands to orchestrate appropriate motor output. The dynamic interactions between incoming sensory information and motor output form the basis of most neuronal computations. Regions in the brain involved in integrating sensory information and processing cognitive mechanisms to guide efferent commands are collectively referred to as association regions and the organizational principles of the association regions remain largely enigmatic. Two such association regions are the posterior parietal cortex (PPC) and temporal cortex. This thesis puts forward multiple new insights into the structural and functional intricacies of rodent and human association regions.

The first part of this thesis (Chapter 2) describes the juxtasomal recording and filling technique, which can be used to record spiking activity from single neurons in vivo followed by identification of its morphology. This is essential to identify the structure-function relationship of single neurons in the association cortices. Additionally the technique can be used across behavioral states, ranging from anaesthetized to freely moving conditions and provides unprecedented information on the link between structure and function for single identified neurons. This is essential to identify the specific role of the various morphological cell types in driving everyday actions. In this section, we additionally describe the use of the juxtasomal technique to measure spiking activity of single neurons to whisker movements in the somatosensory cortex of an anaesthetized rat setup. This is followed by a detailed explanation of the single cell filling process to identify the 3D morphology of the measured cell.

In the next section (Chapter 3) we use the juxtasomal technique in anaesthetized and awake behaving rats to characterize sensorimotor representation of whiskers in the posterior parietal cortex. We show the presence of neurons responsive to passive sensory information from whisker deflections. We further find that whisker ex-afferent information is represented somatotopically in the rat PPC. Recording juxtasomally from head fixed awake behaving rats, we then show that active voluntary whisker motion and object touch related information is also represented in single neurons in rodent PPC. To characterize layer specific coding of whisker sensorimotor behavior, we used linear silicon probes in awake head fixed rats to record spiking activity across all cytoarchitectonic layers of PPC during voluntary free whisking and object touch and revealed layer-specific coding mechanisms during voluntary whisker motion and object touch. More specifically, superficial and deep layer neurons respond with an increase in spiking activity while neurons in middle layers do not show any significant change. Furthermore, the layers show differential tuning preference to whisking phase with the superficial and deep layer neurons spiking preferentially during whisker protraction and neurons in
middle layers modulated by whisker retraction. These results offer the first insights into the layer specific functional organization of the rodent parietal association region during whisker sensorimotor behavior.

Chapter 4 of the thesis attempts to study one aspect of the cognitive control of whisking behavior by the rodent parietal association region. Using in-vivo two-photon calcium imaging on awake head fixed behaving mice, we recorded simultaneously from groups of neurons while performing in a texture discrimination task. We show that neurons in rodent PPC are able to effectively discriminate between two different textures without any association of reward, in naïve conditions. We also find specific neurons encoding information from multiple sensory modalities of audition and whisker somatosensation. Additionally, we find a subgroup of neurons that respond explicitly to absence of any texture. These results show for the first time the presence of texture-omission responsive cells in rodent PPC reinforcing its role in processing attention related control of sensorimotor behavior.

In the final part of the thesis (Chapter 5), we show how the structural and functional features of human temporal association cortex neurons compare to mouse and monkey neurons. By reconstructing complete 3D morphology of single human neurons, filled in fresh living cortical tissue obtained through resection surgery, we provide a comprehensive analysis of the structural features of dendrites across layers of adult human temporal cortex. Comparing cellular architecture with single morphologies from monkey and mice temporal cortex, we demonstrate that human neurons are significantly more complex than neurons from standard laboratory animals (monkey and mouse), with three times higher total dendritic length. We further show that this increased complexity directly impacts information processing capabilities of human neurons by measuring passive electrical properties using computer simulations on dendritic architectures. One conclusion from these findings is that human intelligence is not primarily due to our bigger brains or higher neuronal count, but most likely due to an increased complexity of each neuron resulting in a more efficient information processing unit.

The new results on the organizational principles of rodent and human association cortex presented in this thesis provide a solid framework to guide future investigations on the circuit properties that govern input/output transformations and bridge sensory input to motor output.