Scientists identify neuron types that mediate different behavioral states

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In a recent study, scientists from the Max Planck Florida Institute have provided one of the most comprehensive analyses to date of the detailed architecture of individual functionally characterized neurons in the cerebral cortex, the largest and most complex area of the brain, whose functions include sensory perception, motor control, and cognition.

The study was published in the February edition of the Proceedings of the National Academy of Sciences (*PNAS*). This analysis provides complete three-dimensional reconstructions of the dendritic and axonal anatomy of individual neurons, identifies their target neurons throughout the sensory cortical area and describes the information relayed by these neurons during different behavioral states.

Mapping the connectivity within neuronal networks at the level of individual neurons is a major frontier in neuroscience and an essential step towards understanding how the brain works. “Neurons in the brain are grouped into different cell types, each cell type displaying characteristic anatomical and functional properties”, said Dr. Marcel Oberlaender, a scientist at the Max Planck Florida Institute and the first author of the study. “Identifying the three-dimensional pattern of the axon, the neurons’ ‘sending device’, is essential for defining the properties of neural circuits, and, more broadly, establishes the structural constraints that underlie the computational abilities of the brain.” The findings from this study could lead to a better understanding of how the cortex transforms sensory information into behavioral responses.

Reverse Engineering the Cerebral Cortex

The cerebral cortex is a thin sheet of neurons grouped into layers, which are arrayed parallel to the surface and columns that run perpendicular to the surface and span the depth of the cortex. The neurons within cortical columns share similar response properties and are considered a fundamental unit for processing sensory input. This study is part of a larger research program undertaken by scientists in the Digital Neuroanatomy research group at the Max Planck Florida Institute that aims to reverse engineer the three-dimensional structure and connectivity of neurons in cortical columns. They are focusing on a specialized set of columns in the cortex of the rat that processes sensory input from the facial whiskers, and where each separate whisker has its own specific column.

Dr. Oberlaender said that in related studies they identified nine different cell types and were able to quantify the number of neurons per type, their locations within the cortical column and their functional responses to two behavioral states, whisker motion and whisker touch, respectively. “Most interestingly,” Dr. Oberalender said, “two cell types, located in the same area of a cortical column were selectively active after whisker touch or during whisker motion.” The present study’s detailed three-dimensional reconstructions of the neurons’ ‘sending devices’ revealed that the two cell types also display distinct and characteristic axon projection patterns, providing strong evidence that cell type-specific cortical circuits mediate whisker motion and touch, respectively.

Reconstructing Neurons in Three Dimensions

The most challenging aspect of this new study was the quantitative approach taken by the scientists, an approach that involved the painstaking reconstruction of about 1 meter of axon from the two cell types, with axon diameters being usually smaller than 1 micron. To quantify the three-dimensional projection patterns of individual neurons, the scientists labeled each neuron in the living animal with a light-absorbing marker, which could then be viewed by advanced microscopy imaging techniques.

"We spent five years developing custom-designed imaging techniques and automated reconstruction and analysis tools," admits Dr. Oberlaender, "because the axon of an individual neuron can innervate a volume of more than 10 cubic millimeters of the cerebral cortex and reaches total lengths of up to 10 centimeters. During the process, we generated terabytes of imaging data for each neuron, but we established a workflow that allows reconstructing such complex axonal structures from this large amount of data within less than a week."

The result of all this advanced imaging and reconstruction analysis is a wealth of data on the cell type-specific architecture of the neuronal networks involved in whisker motion and touch, and enables the researches to hypothesize mechanisms that allow rodents to locate objects, and which will ultimately lead to understanding more complex behaviors, such as decision making.

"By integrating this new anatomical data into the reverse engineered model of a cortical column in rodent somatosensory cortex, we hope to be able to perform simulation experiments, which will potentially unravel cellular and network mechanisms that underlie whisker motion, touch and object localization," said Dr. Oberlaender and he concluded, "This will take us one step closer to understanding how the brain transforms sensory information into behavioral responses".

More information: Oberlaender, M., et al. (2011). Three-dimensional axon morphologies of individual layer 5 neurons indicate cell type-specific intracortical pathways for whisker motion and touch. *Proc. Natl.*

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