The brain as image processor and generator

Impact

Modern neuroscientific research is advancing toward a more profound comprehension of the anatomo-functional coupling underlying brain processing. In line with these developments, we used ultra-high field fMRI, a cutting-edge biomedical imaging tool, to non-invasively study human cognitive functioning with great detail in-vivo. The work presented in this thesis interfaces with three important aspects of human vision, namely visual perception (chapter 2), restoring vision loss (chapter 3), and visual mental imagery (chapter 4).

Chapter 2 describes a probabilistic map of the visual brain called visfAtlas; detailing the functional location and variability of category-specific regions in occipito-temporal cortex. While the traditional localizationist concept of "one region–one function" is shifting to a more dynamic vision of the central nervous system as a complex network (Borner et al. 2007, Reijneveld et al. 2007), functional brain atlases remain crucial to assess connections between parcels and to extract network properties. visfAtlas adds a unique parcellation to the existing pool of functional brain atlases and, in addition, supports reproducibility of empirical studies by adding to the standardization of the selection of voxels (i.e. region-of-interest) related to certain cognitive functions. Furthermore, functional brain atlases potentially reduce the number of resources required for empirical research (i.e., obviate the need for functional localizers), as scanning time is a costly parameter of experimental setups.

Chapter 3 presents a novel methodology using Bayesian optimization to explore high-channel cortical implant locations for functional phosphene vision in a large retinotopy fMRI dataset. This software tool addresses some of the scientific and technical challenges that need to be overcome before a visual prosthesis -that interfaces directly with the brain- may one day become a conventional clinical treatment for blindness. Cortical visual prostheses are especially relevant when treatments like retinal prostheses, stem cell transplants, and gene therapy are not available. This work can benefit clinicians and engineers with new insights into neurosurgical restrictions and manufacturing requirements for a high-channel-count, biocompatible, chronically implantable neuronal interface for the visual cortex. Importantly, vision loss is paired with devastating reductions in quality of life, autonomy and economic losses to society due to reduced workforce participation. The next generation of visual cortical prostheses could generate artificial assistive vision that is useful in everyday life, using video footage from a camera that is worn by the patient.

In Chapter 4 we revealed a tight topographic correspondence between visual mental imagery and perception, by exploiting the high spatial resolution of fMRI at 7 Tesla, uncovering the retinotopic organization of early visual cortex and combining it with machine-learning techniques to retrieve imagined letter shapes from the mind's eye. Next to providing new insights into the neural underpinnings of mental imagery, our work can act as a foundation for experimental applications in a clinical setting. Our letter imagery encoding scheme offers a direct and natural way for decoding letters without a need for voluntary muscle control or eye-sight. Therefore, our results might constitute an important first step for the development of a letter-speller BCI that can benefit those with paralysis of voluntary muscles, such as people suffering from locked-in syndrome. In addition, visual imagery ability is retained (or exceptionally vivid; Hahamy et al. 2021) in blind individuals and allows for a novel way to investigate functional reorganization associated with vision loss.

Next to tangible scientific impact in the form of publications, a part of the work has been done in collaboration with NESTOR (Neuronal Stimulation for Recovery of Function), a research project that brought together world-leading academic and industry partners that contribute unique, essential knowledge and expertise. Together, NESTOR collaborators exchanged valuable formation aimed to restore everyday-life abilities after vision was lost, and aided the development of a clinically approved cortical visual prosthesis for the late blind.