Abstract

In recent years, investigating patterns of neural connections and changes in the architecture of functional neural networks, taking place under the influence of various factors, is one of the most important trends in neuropsychology and neurocognitive science. A relatively new area of research carried out in MRI scanners in relation to the resting brain (rs-fMRI) is developing particularly dynamically. In this area, many questions remain unanswered, which become a subject of doctoral dissertation which is presented below. The first question considers the relationship between the neural correlates of the network at rest and the subjective feelings. The next questions concern the description of the functional architecture of the neuronal network of patients suffering from two diverse diseases that have different effects on the nervous system. One of them - multiple sclerosis - lead to neurodegenerative changes, while the other - cataract - does not cause the same type of damage.

The dissertation presents the results based on two research papers, in which I took an active part: Foundation for Polish Science (FNP) Team Net project: Bio-inspired Artificial Neural Networks (POIR.04.04.00-00-14DE/18-00). Cognitive Group (2019 - 2023) and Polish National Science Centre (NCN), SYMFONIA project: The dual role of blue light – an interdisciplinary study on effects of the short wavelength visible light on circadian regulation, neural aspects of cognitive and affective functioning, and on the light contribution to degeneration and pathologies of the retina. (2013/08/W/NZ3/00700) (2013 – 2020). The dissertation consists of three scientific articles in which I am the lead and the corresponding author. The analyzes presented in this paper were conducted in order to understand changes in the functional architecture of the brain as a whole, occurring in a disease leading to degenerative changes versus a disease not associated with degenerative changes in the brain.

In total, 135 rs-fMRI records from 3T Siemens Skrya were analyzed, including patients diagnosed with multiple sclerosis (101 records) and cataract (34 records). For both groups of patients, selection was highly restrictive. Patients with comorbidities such as diabetes, lesion, neurological diseases, psychiatric diseases as well as mental disorders and traumatic brain injuries were excluded from the studies. In case of cataract study, glaucoma as well as other ophthalmological diseases were also excluded. Altogether, eight global and local fMRI measures were used, in every research, in order to identify their correlates with subjective feelings as well as capture functional architecture of neuronal networks. The aforementioned

measures included functional connectivity, regional homogeneity, amplitude of low frequency fluctuations, fractional amplitude of low frequency fluctuations as well as assortativity, eigenvector centrality, local clustering coefficient and mean clustering coefficient. The results were published in three scientific articles.

The first analysis, the results of which were published in the article "Brain Functional Network Architecture Reorganization and Alterations of Positive and Negative Affect, Experiencing Pleasure and Daytime Sleepiness in Cataract Patients after Intraocular Lenses Implantation" aimed at finally identifying functional neural network architecture associated with daytime sleepiness, the ability to experience pleasure as well as positive and negative affect in patients after cataract extraction and intraocular lens implantation. The results revealed local between-session differences in graph indexes associated with effective communication, integration and robustness of the network. The areas of substantial alterations such as superior parietal gyrus are believed to be associated with visuospatial perception, which includes representation and manipulation of objects. Based on the literature, aforementioned structure plays an important role in visual restoration and functional recovery after cataract extraction. In addition, above brain regions showed significant correlation with positive affect, pleasure, anhedonia and daytime sleepiness. The study confirms the influence of the extraction on mood and experiencing pleasure. Moreover, it shows an increased postoperative extensive sleepiness, which encourages further investigation. Overall, the research provides a proof with significant reorganization of neuronal networks associated with cataract extraction and intraocular lens implantation.

The second research focused on capturing the influence of cataract extraction and blue light transmittance on the functional architecture of the brain in elderly patients. According to the previous literature, such an investigation has never happened before, making the study novel and noteworthy. The results were presented in the article „The Influence of Intraocular Lens Implantation and Alterations in Blue Light Transmittance Level on the Brain Functional Network Architecture Reorganization in Cataract Patients„. The analyzes presented larger integration of multiple brain regions, such as superior parietal gyrus, inferior occipital gyrus, cerebellum, vermis as well as supramarginal gyrus and supplementary motor area, which confirms visual, motor and cognitive-related improvement connected with cataract extraction and intraocular lens implantation. In addition, analyzes of preoperative brain architecture suggest excessive compensation mechanisms in the vision, cognitive and motor related areas,

which prevents the disruption of neural network homeostasis after progressive loss of synapses. The alteration in blue light transmittance influences the functional architecture of brain regions responsible for attention and integration of external stimuli. Interestingly, difference in blue light transmittance turned out to be positively correlated with neuronal activity in cerebellum, which has not been associated with blue light before, making the results groundbreaking. Moreover, differences in cerebellum point to a key role of the aforementioned region in overall functioning, which go beyond motor functions. In conclusion, the aforementioned results prove the significant changes in connectivity patterns which are associated with cataract extraction, intraocular lens implantation and blue light transmittance.

The third research (results published in the article „Brain Under Fatigue -Can Perceived Fatigability in Multiple Sclerosis Be Seen on the Level of Functional Brain Network Architecture?") focused on identifying fatigue-related connectivity patterns in the early stage of relapsing-remitting form of multiple sclerosis. It is the world's first study investigating neuronal basis of particularly severe and debilitating disease sign. The results point to hyperconnectivity among posterior Salience Network, suggesting the existence of compensation mechanisms, enabling effective overall functioning. Moreover, the differences in fractional amplitude of low frequency fluctuation were discovered. Noteworthy, the aforementioned regions with FC and fALFF alterations are anatomically or functionally connected to striatal-thalamic-frontal network, also known as the fatigue network. All the results were independent of age, disability level and duration of pharmacological treatment.

Summary:

The results showed significant relationship between the subjective feelings of patients with multiple sclerosis (fatigue) and patients suffering from cataracts (daytime sleepiness, positive and negative affect, as well as the ability to experience pleasure) and the functional architecture of neural networks. Significant reorganization of functional neural networks has also been demonstrated following cataract surgery and intraocular lens implantation, associated with improved vision and blue light transmittance.

The studies included in the thesis are novel and provide a new insight into the domains of clinical neuroscience as well as the functional architecture of neuronal networks. It is the

first study demonstrating the existence of a relationship between subjective feelings and the structure of aforementioned networks. Moreover, studies showed positive effect of cataract extraction and intraocular lens implantation on functional reorganization of the networks above.