PERIODICUM BIOLOGORUM
VOL. 116, No 2, 209–211, 2014

UDC 57:61
CODEN PDBIAD
ISSN 0031-5362

Forum

Neuroplasticity

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Key words: Neuroplasticity, Structural neuroplasticity, Functional neuroplasticity

Received May 22, 2014.

Abstract

„Every man can, if he so desires, become the sculptor of his own brain"

Santiago Ramon y Cajal *(1)*

Neuroplasticity can be defined as brain's ability to change, remodel and reorganize for purpose of better ability to adapt to new situations. Despite the fact that the concept of neuroplasticity is quite new, it is one of the most important discoveries in neuroscience. The fact is that neural networks are not fixed, but occurring and disappearing dynamically throughout our whole life, depending on experiences. While we repeatedly practice one activity such as a sequence of movements or a mathematical problem, neuronal circuits are being formed, leading to better ability to perform the practiced task with less waste of energy. Once we stop practicing a certain activity, the brain will redirect these neuronal circuits by a much known 'use it or lose it' principle. Neuroplasticity leads to many different occurrences, such as habituation, sensitization to a certain position, medication tolerance, even recovery following brain injury.

HISTORICAL OVERVIEW

About 120 years ago, William James was the first to suggest the theory of neuroplasticity in his work Principles of Psychology *(2)*. He suggested that human brain is capable for continuous functional changes. Polish neuroscientist Jerzy Konorski was the first to define the term 'neuroplasticity' in 1948. Konorski suggested a theory by which neurons which have been activated by closeness of an active neural circuit, change and incorporate themselves into that circuit *(3)*. Donald Hebb, a Canadian psychologist established a Hebb's rule, defined also as pre-post coincidence, implying that changes of biochemical processes in one neuron can stimulate neighboring simultaneously activated synapses, this being the basic principle of synaptic plasticity *(4)*. Paul Bach-y-Rita is the pioneer in demonstrating neuroplasticity on actual cases, claiming that healthy regions of the brain can take over the functions of injured parts of the brain. This was the basis of his treatment for people who suffered vestibular damage. He patented an appliance which when connected to one's tongue, stimulates receptors by vibrations in a frequency and amplitude in correlation with pixel analysis from the surroundings *(5-7)*.

Edward Taub supported research and developed first real and applicable treatments for patients. He proved, first using rhesus monkeys, then on humans, that tying up of healthy half of the body in case of

hemiplegia, „forces" the damaged part of the brain to faster rehabilitation *(8-10).*

Michael Merzenich is yet another neuroscientist who left his mark in the field of neuroplasticity. He designed a software for in order to help people with learning difficulties *(11, 12).*

All these scientists had to fight against an academic dogma which disapproved the existence of adult brain neuroplasticity, except during developmental phase. Until the Decade of the brain (1990-2000), the word 'neuroplasticity' itself, lead to articles not being published in prestigious journals. When asked, Eric Kandel, a Nobel Prize winner in medicine, said that neuroplasticitiy is what marked the Decade of the brain.

TYPES OF NEUROPLASTICITY

Neuroplasticity is a general term, defining the fact that the brain changes, recognizing the need for further definition of the term. We distinguish structural from functional neuroplasticity.

a) Structural neuroplasticity

Synaptic plasticity refers to changes in the strength between neurons (synapses), chemical or electric meeting points between brain cells. Synaptic plasticity is a general term, and the name itself has no meaning other that something changed within the synapse, but can include many specific processes such as long-term changes in the number of receptors for certain neurotransmitters, or changes where some proteins are being synthetized more within the cell.

Synaptogenesis refers to formation and fitting of synapse or group of synapses into a neural circuit *(13).* Structural plasticity is a normal marking of fetal neurons during brain development and is called developmental plasticity, including neurogenesis and neuronal migration.

Neuronal migration is a process in which neurons travel from their 'place of birth' in fetal ventricular or subventricular zone, towards their final position in the cortex.

During development, brain areas become specialized for certain tasks such as processing signals form the surrounding areas through sensory receptors. For example, in occipital brain area, the fourth layer of cortex hypertrophies in order to receive signals from the visual pathway *(14).*

Neurogenesis is formation of new neurons. It is a process which mainly takes place during brain development, even though in the last decade neurogenesis was found in adult brain as well. On the other hand, neuronal death occurs throughout life, due to brain damage or programmed cell death. Other forms of structural neuroplasticity include changes in white or gray matter density which can be visualized by magnetic resonance.

b) Functional neuroplasticity

Functional neuroplasticity depends upon two basic processes, learning and memory. They also represent a special type of neural and synaptic plasticity, based on certain types of synaptic plasticity causing permanent changes in synaptic effectiveness *(15).* During learning and memory permanent changes occur in synaptic relationships between neurons due to structural adjustments or intracellular biochemical processes.

NEUROBIOLOGICAL BASIS OF NEUROPLASTICITY

When looking at neuroplasticity on molecular level, all types of synaptic plasticity share neurotransmitter exocytosis modulation, on the level of one single synapse or among a larger neuronal network. Synaptic plasticity mainly depends on receptors binding neurotransmitters. Mental events activate a large neural molecular cascade, including regulatory factors referring to DNA and RNA *(16).* Research on long term changes within the synapse consider different types of memory based on different mechanisms. Within the cortex, glutamate receptors paly the key role, as glutamate is the most important excitatory neurotransmitter. If several impulses, from neighboring neurons, in a very short time, activation of metabotropic glutamate receptors (NMDA) occurs. This enables calcium influx which participates in protein synthesis, and permanently changes postsynaptic neuron *(17).*

REMODELING OF NEURONAL CIRCUITS FOLLOWING BRAIN DAMAGE

After establishing the fact that brain has a possibility of remodeling its own neural maps, the main question for neurorehabilation medicine is how to direct this neuroplasticity to regain lost functions caused by a neurologic deficit. This emphasizes the need to neuroanatomically define every neurologic lesion. When we know which neural pathway is damaged, we can start looking for bypasses.

a) Movement rehabilitation

When we learn complex movements, the brain firstly recognizes basic motoric movements, and divides them and stores them into a given model which is then remembered. The same network of neurons will activate every time we observe, think, or make a certain movement, or hear sounds which remind us of that movement. If we focus on repetitive movements, it is important to understand the purpose of the movement. For example, for a patient practicing hand pronation, the movement itself is not the purpose; the purpose is for him to be able to open the door again. This way we can stimulate other neuronal circuits which can lead to execution of this final goal. Neurological rehabilitation must focus on expediency of

the movement. This makes familiarizing with patient's habits before stroke very important. Most complex movements that we perform, we were first observing during childhood. It is helpful to repeat these movements during rehabilitation process. Ventral premotor cortex and base of parietal lobe are cortical areas belonging to mirror neuron system *(18).* These areas have shown to be great neuroanatomical target areas for rehabilitation exercises. The goal is to reach their activation through any connected healthy part of the cortical network. The mirror neuron system will activate differently in every person, depending on individual's level of practice of specific movement. For example, if a patient played a guitar and danced tango prior to stroke, the observation of these activities itself will strongly activate his mirror neurons, which leads to stimulation of larger network area and reconnection of large number of synapses.

b) Neuronal processing of different signals

In 1821, a French soldier named Charles Barbier, visited a Royal institution „night writing", in Paris, presenting his invention, a code of 12 dots which offer possibilities to soldiers to communicate and share information on the battle field, without the need for speech. Usage of the code showed to be too difficult for soldiers, but not for a blind boy from that institution, Louis Braille. Braille lowered the number of dots from 12 to 6, and published the first Braille book in 1829. In 1839 he added mathematical and music symbols *(19).* How can a blind person process and translate position of the dots so fast? If the experience is changing dramatically or parts of the brain are damaged, parts of the brain can change their function without structural changes. From this example, visual cortex in a blind person, if it's not receiving information from the visual pathway, it can process the sense of touch. 150 years later, Uhl and his coworkers proved that tactile reading in blind subject activates the occipital, visual part of the cortex *(20).* Remodeling of brain maps after brain damage is a revolutionary term which opened a pathways for new understanding of neurorehabilitation *(21).* After accepting the fact, the future of neurorehabilitation lies in defining neural pathways and ways we can regain lost function by using bypass pathways in the brain *(22).*

CONCLUSION

Our brain is constantly changing during lifetime. During fetal development structural changes are dominant, such as neurogenesis and migration of neurons, while in adult brain the dominant type of neuroplasticity is functional, allowing the brain to constantly adapt to environment and injury. The greatest challenge for neurorehabilitation in the future is finding and defining major and minor neural pathways, and then aim to support neuroplasticity of compensatory neural circuits.

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