LEARNING EXPERIENCE AND NEUROPLASTICITY – A SHIFTING PARADIGM

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ABSTRACT. This paper is a summary of significant findings from the last decades concerning the brain's plasticity and its links and relevance for the learning processes. Until two decades ago, there were few things known about neuroplasticity. Scientists referred to neuroplasticity referring to the maturing brain during childhood. Also they recognized it when compensating altered functions in brain damage cases, through maximizing the functionality of intact brain areas and improving the functional reorganization of the brain. The research of the last decades indicates that neuroplasticity is present all through life, whenever we are learning or memorizing something new. Neuroplasticity is considered to be one of the most important discoveries of the twentieth century.

This paper is a summary of the significant findings from the last decades concerning the brain's plasticity and its links and relevance for the learning processes[2].

KEYWORDS: learning, neuroplasticity, cognition, development.

The State of the Art

Neuroplasticity, cortical plasticity or cortical re-mapping refer to the ability of the brain to reorganize neural pathways according to new experiences. It is the capacity to change through learning experiences, and learning means acquiring new knowledge and new skills, benefiting from instructions or experience. For the phenomena of learning, memorizing, acquiring new knowledge and skills correspond to functional changes in the brain.

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[2] It shows some commonalities with a study I published on a similar topic Joja, O. (2008), '*Learning and Creativity: Recent Research Developments in Neurosciences*'. Extended paper for the volume of the Conference 'Teaching and Education' at the Titu Maiorescu University Bucharest.

Research developments confirmed that neuroplasticity is present all through our lives, whenever we are learning or memorizing something new. Empirical data have been overthrowing the centuries-old notion that the human brain would be immutable. Neuroplasticity has been considered as one of the most extraordinary discoveries of the 20th century[3].

The ideea o neuroplasticity has been launched in 1890 by William James, in his *The Principles of Psychology*, but it has been ignored for a long time. The consensus among neuroscientists was that brain structure is relatively immutable after the critical period of the early childhood. This belief has been challenged by findings revealing that many areas of the brain, and not only one (the hippocampus), as was erroneously thought, remain plastic even in adulthood[4].

The Canadian psychologist Donald Olding Hebb (1904–1985) has been considered as the father of neuropsychology, due to his study *The Organization of Behaviour*[5]. Hebb's main topics have been the neural networks and the learning processes. He tried to understand and explain the brain's function and its relationship to the mind, challenging through evidence-based data the old mind and body dualism, exploring the biological function of the brain correlated to behavior. Hebb's well known thesis has been recalled by recent science and is still often quoted as Hebb's postulate: "Neurons that fire together wire together", a thesis which explains the adaptation of neurons during the learning process. Hebb managed to describe the basic mechanisms of synaptic plasticity, wherein an increase in synaptic efficacy arises from presynaptic neuron's repeated and persistent stimulation of the postsynaptic cell. The theory assumes that cell assemblies constitute the foundation of memory "engrams" and therein learning will be best described as: *When an axon of cell A is near enough to excite cell B and repeatedly or persistently takes part in firing it, some growth process or metabolic change takes place in one or both cells such that A's efficiency, as one of the cells firing B, is increased*[6]. Just two decades ago, scientists still

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3 Norman Doidge, *The Brain That Changes Itself: Stories of Personal Triumph from the Frontiers of Brain Science* (James H. Silberman Books), Viking Adult, 2007.

4 Pasko Rakic, "Neurogenesis in adult primate neocortex: an evaluation of the evidence", *Nature Reviews Neuroscience*, 3(1), 2002, pp. 65–71.

5 Donald Olding Hebb, *The Organization of Behaviour: a neuropsychological theory*, John Wiley & Sons, New York, 1949.

6 Donald Olding Hebb, *The Organization of Behaviour: a neuropsychological theory*, John Wiley & Sons, New York, 1949.

believed that the ability of neuroplasticity would only occur under distinct conditions, i.e. at the beginning of life, when the immature brain organizes itself; in case of brain injury, to compensate for lost functions or maximize remaining functions and through adulthood, whenever something new is learned and memorized[7].

In the year 2000, Arvid Carlsson, Paul Greengard and Eric Kandel shared the Nobel price for their contribution in studying the signal transduction in the nervous system. The three Nobel Laureats in Physiology and Medicine have made pioneering discoveries concerning one type of signal transduction between nerve cells, referred to as slow synaptic transmission. These discoveries have been crucial for an understanding of the normal function of the brain and how disturbances in this signal transduction can give rise to neurological and psychiatric diseases[8]. With the nervous system of a sea slug „as (an) experimental model, he (Eric Kandel) has demonstrated how changes of synaptic function are central for learning and memory. Protein phosphorylation in synapses plays an important role for the generation of a form of short term memory. For the development of a long term memory a change in protein synthesis is also required, which can lead to alterations in shape and function of the synapse"[9]. Neuroimaging research of the past decades – marked by the 2000 Nobel Prize Laureate in neurosciences Eric Kandel[10] – confirmed the human brain's power of neuroplasticity and its ability to change its structure and function in response to experience. Every new experience demands an effort of adaptation, inducing the process of integrating new information, i.e. a the *learning process*. Learning, as well as thinking and acting, may change both the brain's functional and physical anatomy. Neuroplasticity is part of several important functions, including learning, memory, and response to novelty[11].

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7 Pascale Michelon, (2008), *Brain Plasticity: How learning change your brain*, http://www.sharpbrains.com/blog/2008/02/26/brain-plasticity-how-learning-changes-your-brain/, [24 Jul 2012].

8 Press Release Nobelförsamlingen Karolinska Institutet The Nobel Assembly at the Karolinska Institute, 9 October 2000.

9 *Ibidem.*

10 Eric Kandel, psychiatrist, neuroscientist and professor of biochemistry and biophysics at the Columbia University College of Physicians and Surgeons. He was a recipient of the 2000 Nobel Prize in Physiology or Medicine for his research on the physiological basis of memory storage in neurons.

11 Ronald S. Duman, Shin Nakagawa, and Jessica Malberg, "Regulation of Adult Neurogenesis by Psychotropic Drugs and Stress", *The Journal of Pharmacology and Experimental Therapeutics*, 299(2), 2001, pp. 401–7.

We know from animal (rodent) studies, initiated during the 1960's, that rodents raised in an enriched environment have a larger cortex, more cellular connections, and are developing new brain cells (neurogenesis) in the hippocampus[12]. Starting with the 1990's, such data have been replicated on humans[13]. Still, the mechanisms by which new neurons are generated and could contribute to brain repair are poorly understood[14].

A series of studies indicated for rodents, non-human primates and humans that enriched environments[15] may produce not only a host of structural and functional changes in the brain[16], but also a significant increase in the hippocampal neurogenesis[17]. It appears that, the hippocampal neurogenesis in particular may play a role in the neuroadaptation associated with pathologies, such as cognitive disorders and depression[18]. „Increased cell birth is associated with learning, memory, exercise, and antidepressant treatment, and decreased rates of cell proliferation are seen in response to stress and during aging. In addition, drugs, as well as hormones and growth factors, can regulate the rate of cell proliferation"[19].

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12 Gerd Kempermann, Georg H. Kuhn, and Fred H. Gage, "More hippocampal neurons in adult mice living in an enriched environment", *Nature*, 386 (6624), 1997, pp. 493–495.

13 Peter S. Eriksson, Ekaterina Perfilieva, Thomas Björk-Eriksson Ann-Marie Alborn, Claes Nordborg Daniel A. Peterson, Fred H. Gage, 'Neurogenesis in the adult human hippocampus', *Nat Med*., 4(11), 1998, pp. 1313–1317.

14 Henriette Van Praag, Gerd Kempermann, Fred H. Gage (1999), *Running increases cell proliferation and neurogenesis in the adult mouse dentate gyrus*, Nature America Inc., http://neurosci.nature.com, [25 Jul 2012].

15 Mark R. Rosenzweig, David Krech, Edward L. Bennett, and Marian C. Diamond, "Effects of environmental complexity and training on brain chemistry and anatomy", *Journal of Comparative Physiological Psychology*, 55, 1962, pp. 429–437.

16 William T. Greenough, "Experiential modification of the developing brain", *American Scientist*, 63, 1975, pp. 37–46, 13. Janice M. Juraska, Jonathan M. Fitch, Constance Henderson, & Natalie Rivers, "Sex differences in the dendritic branching of dentate granule cells following differential experience", *Brain Research*., 333, 1985, pp. 73–80. 14. Janice M. Juraska, Jonathan M. Fitch, & Donna L. Washburne, "The dendritic morphology of pyramidal neurons in the rat hippocampal CA3 area II. Effects of gender and experience", *Brain Research*., 479, 1989, pp. 115–119.

17 Gerd Kempermann, Georg H. Kuhn, Fred H. Gage, "More hippocampal neurons in adult mice living in an enriched environment", *Nature*, 386, 1997, 493–495.

18 Eleni Paizanis, Sabah Kelaï, Thibault Renoir, Michel Hamon, Laurence Lanfumey, "Life-long hippocampal neurogenesis: environmental, pharmacological and neurochemical modulations", *Neurochemical Research*, 32 (10), 2007, pp. 1762–71.

19 Van Praag et al., 2000.

Enriched environment

The factors underlying the positive actions of an enriched environment include a combination of social interactions, learning and memory, as well as behavioral activity (van Praag et al., 2000[20]).

The standard definition of an enriched environment is "a combination of complex inanimate and social stimulation"[21]. "This definition implies that the relevance of single contributing factors can not be easily isolated, but there are good reasons to assume that it is the interaction of factors that is an essential element of an enriched environment, not any single element that is hidden in the complexity[22].

There are different cognitive theories trying to explain how environmental enrichment influences the development of the brain. The most important approaches are (1) *the arousal hypothesis*[23], which considers the prominence of the 'arousal response' of animals, when confronted with novelty and environmental complexity; and (2) *the learning and memory hypothesis*[24], in which the cellular mechanisms underlying the learning processes are prominently considered. The learning-memory hypothesis is favoured by many investigators, although, according to van Praag et al. (2000) it is difficult to prove that the neural consequences of the enriched environment are related to learning rather than to increased voluntary motor behaviour" [25].

As the experiences we are going through are changing the patterns of our brain, our questioning concerns the meaning of such findings and their consequences, in other words: how such data are changing the perspective on human life.

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20 *Idem* consequences-van-praag.pdf.

21 Rosenzweig, M. R., Bennett, E. L., Hebert, M. & Morimoto, H., "Social grouping cannot account for cerebral effects of enriched environments", *Brain Research*. 153, 1978, pp. 563–576 (1978) / apud van Praag et al., 2000.

22 Henriette Van Praag, Gerd Kempermann, Fred H. Gage (2000), "Neural consequences of environmental enrichment", *Nat Rev Neurosci*., 1(3), 2000, pp. 191–8.

23 Roger N. Walsh, Robert A. Cummins, "Mechanisms mediating the production of environmentally induced brain changes", *Psychol. Bull.,* 82, 1975, pp. 986–1000.

24 Henriette Van Praag, Gerd Kempermann, Fred H. Gage, "Running increases cell proliferation and neurogenesis in the adult mouse dentate gyrus", *Nature Neurosci.,* 2, 1999, pp. 266–270. (Studied the effects of components of the enriched environment such as learning and motor activity on neurogenesis. No effect of learning was observed. However, this is the first study to show that voluntary activity on a wheel increases cell proliferation and survival in the dentate gyrus./ apud van Praag et al., 2002).

25 *Ibidem,* pp. 192.

Further data on neuroplasticity

A much cited book published by Norman Doidge in 2007[26], describes numerous examples of functional shifts in brain, which are due to neuroplasticity. Plasticity phenomena have been registered at bilinguals, as indicated by Mechelli et al.[27] This group of researchers showed that: "earning a second language increased the density of grey matter (cortex) in the left inferior parietal cortex and, the degree of structural reorganization appeared to be modulated by the proficiency attained and the age at the acquisition of the language. This relation between the grey-matter density and the language performance may represent a general principle of brain organization", concluded Mechelli et al. in their study.

Significant changes also occur in musicians in comparison to non-musicians. Gaser and Schlaug (2003)[28] compared professional musicians, practicing at least one hour per day, to two other groups, amateur musicians and non-musicians. They found that the gray matter volume was the highest in professional musicians, intermediate in amateur musicians, and lowest in non-musicians, in several brain areas which are specifically involved in playing music: in motor, auditory, and visual-spatial brain regions. Gaser and Schlaug concluded that these multiregional differences might represent structural adaptations in response to long-term skill acquisition and the repetitive rehearsal of those skills. Moreover, they considered that this latter hypothesis is supported by the strong association between the structural aspects, the musician status, and the practice intensity, paralleling animal data that indicated structural changes in response to long-term motor training[29].

Other data on functional plasticity came from the area of research concerning acquiring information. Draganski et al.[30], a group of researchers from the University of Regensburg, Germany showed

26 Norman Doidge, *The Brain That Changes Itself: Stories of Personal Triumph from the Frontiers of Brain Science* (James H. Silberman Books), Viking Adult, 2007.

27 Andrea Mechelli, Jenny T. Crinion, Uta Noppeney, John O'Doherty, John Ashburner, Richard S. Frackowiak & Cathy J. Price, "Neurolinguistics: Structural plasticity in the bilingual brain", *Nature,* 431, 2004,| doi:10.1038/431757a.

28 Christian Gaser and Gottfried Schlaug, "Brain Structures Differ between Musicians and Non-Musicians", *The Journal of Neuroscience*, 23(27), 2003.

29 *Idem*.

30 Bogdan Draganski, Christian Gaser, Gerd Kempermann, H. Georg Kuhn, Jürgen Winkler, Christian Büchel,5 and Arne May, "Temporal and Spatial Dynamics of Brain Structure Changes during Extensive Learning", *Journal of Neuroscience,* 26 (23), 2006, pp. 6314–6317.

that extensive learning of abstract information can also trigger some plastic changes in the brain. They used the method of *voxel-based morphometry* to detect possible structural brain changes associated with learning. Magnetic resonance images were obtained at three different moments during the learning for the examinations of medical students. Results showed that during the learning period the gray matter increased significantly, bilaterally, in the posterior and lateral parietal cortex. Authors concluded that the acquisition of a great amount of highly abstract information may be related to a particular pattern of structural gray matter changes in some brain areas.

Learning Processes in Developmental Psychology

One of the definitions of neuroplasticity is that of the selective organization of connections between neurons in our brains, meaning that when people repeatedly practice an activity or repeatedly access certain information of the memory, the neural networks are shaping themselves according to that very pattern of activity or memory. Throughout this process, electrochemical pathways are reinforced and those groups of neurons which are firing together, are also wiring together, as Hebb formulated it.

When people stop practicing certain activities or stop reactivating certain information, the brain will eventually eliminate, or *prune* the connections which formed the corresponding pathways.

Jean Piaget (1896–1980) considered, on behalf of long-termed and complex observations and experiments, that infants have no innate knowledge, and neither a sense of the "object permanence"[31], beyond their actual senses. Piaget believed, just as many neuroscientists do today, that infants are gradually assembling knowledge from experience. This constructivist approach has much influenced the psychology of the last century.

Starting in the mid–1980's, a series of experiments and observations have been undertaken, in which infants were shown physical events that seemed to violate basic concepts as gravity, solidity and contiguity. These experiments parted developmental psychologists

[31] Jean Piaget, a Swiss psychologist who first studied object permanence in young infants, argued that object permanence is one of an infant's most important accomplishments. Without this concept, objects would have no separate, permanent existence. In Piaget's theory of cognitive development infants develop this understanding by the end of the "sensorimotor stage," which lasts from birth to about 2 years of age. Apud Santrock, John W. (2008), *A topical approach to life-span development* (4 ed.), New York City: McGraw-Hill.

into *nativists*, claiming that infants already arrive with some knowledge of the physical world and a rudimentary programming for mathematics and language, and *constructivists*, sustaining an all over learning hypothesis, e.g. viewing the cognitive development as a progressive elaboration of increasingly complex structures.

Researchers around Sylvain Sirois from the University of Manchester (UK) repeated some of the experiments, also carefully registering infants' emotions and motor reactions. With this neoconstructivist approach, they proposed a unifying framework for understanding the cognitive development. The guiding principle was what they called *context dependence*, within and between levels of organization of the human's mind throughout its development. They proposed three mechanisms guiding "the emergence of representations: *competition, cooperation, and chronotopy*, which themselves allow for two central processes: proactivity and progressive specialization"[32].

A series of brain-imaging studies showed that the brain has a „visual buffer" that continues to represent objects after they have been removed. So, when infants encounter novel or an unexpected event and "there is a mismatch between the older buffer and the new information they are getting at that moment, they have to adapt the old structures to the new information. That means that they have to resolve that mismatch by clearing (resetting) the buffer"[33]. Sirois et al. (2007) are concluding that learning essentially means a laborious business of resolving mismatches[34].

Learning, the self and consciousness

Joseph LeDoux is a well-known researcher and a professor for Neural Science at the New York University. In his book *Synaptic Self. How Our Brain Becomes Who We Are*[35] he is explaining the synaptic basis of the brain and the complicated relationship between genes and environment. LeDoux asks how we should conceive this

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32 Sylvain Sirois, Michael Spratling, Michael S. Thomas, Gert Westermann, Denis Mareschal, Mark H. Johnson, "Précis of neuroconstructivism: how the brain constructs cognition", *Behav Brain Sci.*, 31(3), 2008, pp. 321–31; discussion 331–56.

33 Michael Brunton, (2007), *Lessons for Handling Stress*, Time Magzine, http://www.time.com/time/magazine/article/0,9171,1580382,00.html. [26 Jul 2012].

34 Sylvain Sirois, Iain Jackson, "Social cognition in infancy: a critical review of research on higher-order abilities", *European Journal of Developmental Psychology*, Vol. 4, 2007.

35 Joseph LeDoux, Das Netz der Persönlichkeit, *Wie unser Selbst entsteht*, Walter Verlag, Düsseldorf und Zürich, 2003, pp. 132.

(pre-existing) basis, if the development of synapses is an epigenetic process. There seems to be no good reason for not admitting that the function of some networks would be more or less settled through inheritance and this appears to be true especially in the case of predispositions which allow the integration of certain kinds of information.

LeDoux describes learning as a timeless process, running through all our lives. It appears as being exaggerated to suppose that certain learning processes have to be undertaken at a precise early age and, if missed, the brain would not be able to acquire later on that specific information. In that context, LeDoux analyses data which indicate that the infants' brain is changing every time he is learning something new and that this very change will further help him to acquire new information[36]. The early years are most important not because there would be no chance for recuperating, but because the information and schema assimilated during that time are basic for further learning.

For LeDoux there is a particular relationship between enduring learning and the development of the self. The self becomes a self for most of its part throughout the process of re-shaping old memories into new ones. Accordingly, learning means producing (new) memories, a process that depends upon things that we have learned before[37]. Thus, the self appears to be partly a product of memory and it is kept (maintained) throughout memory, implying *explicit*, as well as *implicit* forms of memory.

Another interesting view upon learning linked to neuroplasticity is that of Antonio Damasio, the director of the *Brain and Creativity Institute* at the University of Southern California. Damasio pertains to the oddness of some philosopher's believe that solving the problem of consciousness would be beyond the reach of human intelligence[38]. He considers such a believe as fitting the sensible intuition about our mind being something different, separable from the brain. But, says Damasio, the fact that the intuition is sensible does not make this argument being right. In his view, the gene networks organize themselves producing complex organisms and the brains of these

[36] Alison Gopnik, Andrew N. Meltzoff, Patricia P. Kuhl,*The Scientis in the Crib,* New York, Morrow, 1999

[37] Joseph LeDoux, Das Netz der Personlichkeit, *Wie unser Selbst entsteht. Deutscher Taschenbuch*, Verlag Walter, 132 Verlag, Duseldorf und Yurich, 2003. pp. 134.

[38] Antonio Damasio, *Looking for Spinoza: Joy, Sorrow, and the Feeling Brain*, Harcourt, 2003.

organisms enable what we call *behavior* and their further evolution, unto growing their complexity.

Therein, the brain appears to be working out a sort of sensory and motor maps, which are representing the environments the brain interacts with. Inside such interactions, our mind's maps are responding to and are being modified by the environment. He explains how the networks of synapses are being wired to reflect a world, implying the additional trait of each person's specific construction[39].

Behavior, feelings, and emotions are colored by genes. But they are also influenced and modeled by the environment, perhaps primarily in the context of interpersonal relationships. One suggestion comes from the social neglect data (missing relationships), which may have as consequence the loss of neurons and the deconstruction of synapses, the latter, in turn, producing emotional disturbances. And the cognitive development of humans appear to depend enormously upon the emotional stability which enhances the capacity for learning through mechanisms such as curiosity and motivation.

Conclusions

In summary, changes in the messages the brain receives may massively contribute to the brain's development, e.g. to its cognitive development. Last decades' research has indicated that they may also alter the structure of the brain and its functioning. The neuroimaging data have been tremendously challenging our knowledge in this area during the last decades. The developmental approach reconsidering constructivism for understanding the infant's cognitive development has been partly linked with neuroimaging data. The new ways of conceptualizing psychological processes, and especially learning, have changed our view upon the architecture and the functioning of the human mind. Some of the relevant data are summarized in this paper.

Bibliography

[1] Brunton Michael, (2007), *Lessons for Handling Stress*, Time Magazine, http://www.time.com/time/magazine/article/ 0,9171,1580382,00.html. [26 Jul 2012].

[2] *Damasio Antonio, Looking for Spinoza: Joy, Sorrow, and the Feeling Brain, Harcourt, 2003.*

[3] *Damasio Antonio, Self Comes to Mind: Constructing the Conscious Brain, Pantheon, 2010.*

39 Antonio Damasio, *Self Comes to Mind: Constructing the Conscious Brain*, Pantheon, 2010.

[4] Doidge Norman, *The Brain That Changes Itself: Stories of Personal Triumph from the Frontiers of Brain Science* (James H. Silberman Books), Viking Adult, 2007

[5] Draganski Bogdan, Gaser Christian., Kempermann Gerd, Kuhn H. Georg, Winkler Jürgen, Büchel Christian, May Ame, "Temporal and Spatial Dynamics of Brain Structure Changes during Extensive Learning", *Journal of Neuroscience,* 26 (23), 2006, pp. 6314–6317.

[6] Duman Ronald S., Malberg Jessica & Nakagawa Shin, "Regulation of Adult Neurogenesis by Psychotropic Drugs and Stress", *The Journal of Pharmacology and Experimental Therapeutics*, 299(2), 2001, pp. 401–7.

[7] Eriksson Peter S., Perfilieva Ekaterina, Björk-Eriksson Thomas, Alborn Ann-Marie, Claes Nordborg, Peterson Daniel A., Fred H. Gage, "Neurogenesis in the adult human hippocampus", *Nat Med*., 4(11), 1998, pp. 1313–1317.

[8] Gaser Christian. and Schlaug Gottfried, "Brain Structures Differ between Musicians and Non-Musicians", *The Journal of Neuroscience*, 23(27), 2003.

[9] Gopnik Alison, Meltzoff Andrew N., Kuhl Patricia P., *The Scientis in the Crib,* New York, Morrow, 1999.

[10] Greenough William T., "Experiential modification of the developing brain", *American Scientist*, 63, 1975, pp. 37–46.

[11] Hebb Donald Olding, *The Organization of Behaviour: a neuropsychological theory*, John Wiley & Sons, New York, 1949.

[12] Juraska Janice M., Fitch Jonathan M., Henderson Constance & Rivers Natalie, "Sex differences in the dendritic branching of dentate granule cells following differential experience", *Brain Research*., 333, 1985, pp. 73–80.

[13] Juraska Janice M., Fitch Jonathan M., & Washburne Donna L., "The dendritic morphology of pyramidal neurons in the rat hippocampal CA3 area II. Effects of gender and experience', *Brain Research*., 479, 1989, pp. 115–119.

[14] Kempermann Gerd, Kuhn Georg H. & Fred H. Gage, "More hippocampal neurons in adult mice living in an enriched environment", *Nature*, 386 (6624), 1997, pp.493–495.

[15] *LeDoux Joseph, Personlichkeit Das Netz der, Wie unser Selbst entsteht. Deutscher Taschenbuch, Verlag Walter, 132 Verlag, Duseldorf und Yurich, 2003. pp. 132.*

[16] LeDoux Joseph, Persönlichkeit Das Netz der, *Wie unser Selbst entsteht*, Walter Verlag, Düsseldorf und Zürich, 2003, pp. 134.

[17] Mechelli Andrea, Crinion Jenny T., Noppeney Uta, O'Doherty John, Ashburner John, Frackowiak Richard S., & Price Cathy J., "Neurolinguistics: Structural plasticity in the bilingual brain", *Nature,* 431**,** 2004, doi:10.1038/431757a.

[18] Michelon Pascale (2008), *Brain Plasticity: How learning change your brain*, http://www.sharpbrains.com/blog/2008/ 02/26/brain-plasticity-how-learning-changes-your-brain/, [24 Jul 2012].

[19] Paizanis Eleni, Kelaï Sabah, Renoir Thibault, Hamon Michel, Lanfumey Laurence, "Life-long hippocampal neurogenesis: environmental, pharmacological and neurochemical modulations", *Neurochemical Research*, 32 (10), 2007, pp. 1762–71.

[20] Rakic Pasko, "Neurogenesis in adult primate neocortex: an evaluation of the evidence", *Nature Reviews Neuroscience*, 3(1), 2002, pp. 65–71.

[21] Rosenzweig Mark R, Krech David, Bennett Edward L. & Diamond Marian C., "Effects of environmental complexity and training on brain chemistry and anatomy", *Journal of Comparative Physiological Psychology*, 55, 1962, pp. 429–437.

[22] Rosenzweig Mark R., Bennett Edward L., Hebert Marie & Morimoto Hiromi, "Social grouping cannot account for cerebral effects of enriched environments", *Brain Research*. 153, 1978, pp. 563–576 (1978) / apud Van Praag et al., 2000.

[23] Santrock John W., *A topical approach to life-span development* (4 ed.). New York City: McGraw-Hill, 2008.

[24] Sirois Sylvain, Spratling Michael, Thomas Michael S., Westermann Gert, Mareschal Denis, Johnson Mark H., *Précis of neuroconstructivism: how the brain constructs cognition*, Behav Brain Sci., 31(3), 2008, pp. 321–31; discussion 331–56.

[25] Sirois Sylvain, Iain Jackson, "Social cognition in infancy: a critical review of research on higher-order abilities", *European Journal of Developmental Psychology*, Vol. 4, 2007.

[26] Van Praag Henriette, Kempermann Gerd, Gage Fred H., (1999), *Running increases cell proliferation and neurogenesis in the adult mouse dentate gyrus*, Nature America Inc., http://neurosci.nature.com, [25 Jul 2012].

[27] Van Praag Henriette, Kempermann Gerd, & Gage Fred H., "Running increases cell proliferation and neurogenesis in the adult mouse dentate gyrus", *Nature Neurosci.,* 2, 1999, pp. 266–270.

[28] Van Praag Henriette, Kempermann Gerd, Gage F.H. (2000), "Neural consequences of environmental enrichment", *Nat Rev Neurosci*., 1(3), 2000, pp. 191–8.

[29] Walsh Roger N. & Cummins Robert A., "Mechanisms mediating the production of environmentally induced brain changes", *Psychol. Bull.,* 82, 1975, pp. 986–1000.