Overview of Neuroplasticity Research

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Abstract

Neuroplasticity is the brain's ability to change itself. While it always has been understood that the brain changed significantly during childhood, recent evidence shows that neuroplasticity is a lifelong process. That being said, neuroplasticity is most active during the critical period of one's youth. Neuroplasticity plays a key role in the recovery of stroke and spinal cord injuries. It plays a role in both causing and treating addictive disorders. Neuroplasticity is hindered during depression and times of chronic stress. Treatments of depression are successful in part because they enhance neuroplasticity. Neuroplasticity can be enhanced by physical exercise and living in enriched environments. Ultimately, neuroplasticity requires conscious effort to work.

Keywords: Neuroplasticity, stroke, spinal cord injuries, depression, stress, addiction

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Until recently, the orthodoxy of neuroscience was that “the brain can change during the juvenile period, once that period is over, its structures are fixed" (Lillard & Erisir, 2011). The mind was believed to be set, and a damaged brain could never recover. Recent research on the topic, coined neuroplasticity, has proven that the brain indeed can change significantly. This opens up new possibilities when it comes to the medical treatment of ailments such as mental illness, addiction, stroke and spinal cord injuries (Lillard & Erisir, 2011). It also can change our conception of how we learn, both at the juvenile and the adult levels. This paper is an overview of what neuroplasticity is, how it applies to medical treatment, and how it is can be enhanced. Neuroplasticity is a promising branch of medical science that should be researched more.

What is Neuroplasticity?

“Neuroplasticity” is the concept that the brain and the nervous system can change at a structural level (Lillard & Erisir, 2011). Originally, it was believed that major structural changes in the brain lasted up to puberty. Now it is believed that nervous system change is lifelong (Lillard & Erisir, 2011). There are multiple kinds of neuroplasticity that often run in parallel and can be influenced by time and the environment (Cramer, et al., 2011). The idea that the brain can change brings hope to people who have neurological disorders and allows anyone at anyone age to optimize their mind. “Even if our brains are not optimally wired to learn a certain task, we may still invest our motivation and energy into activities of our choice and compensate by increased effort and training intensity” (Herholz, 2013). It turns out, you can teach an old dog new tricks.

Neuroplasticity has many different elements including the following. Neurogenesis is the creation of new neurons. Axon and dendrite growth is the growth of nerve cells and their interconnection between other neurons. Synapses, the connections between neurons, can also be modified. Furthermore, the amount of myelination of nerves can change, affecting the speed and efficiency of nerve networks (Lillard & Erisir, 2011). Neuroplasticity "can be ongoing in parallel" (Cramer, et al., 2011). It is "experience dependent, time-sensitive and strongly influenced by features of [one's] environment" (Cramer, et al., 2011).

Critical Stages

During the early stages of a person's life, the brain makes "large-scale axonal and dendritic extensions and reorganization" as opposed to the small-scale changes that occur later in life (Lillard & Erisir, 2011). Scientists call this period of neuroplasticity a sensitive or critical period. Several forms of neuroplasticity are at their peak in a developing brain (Cramer, et al., 2011). For example, people who learn second languages before the age of seven usually speak without an accent. Those who learn second languages later in life have far more difficulties (Lillard & Erisir, 2011). The same is true for social skills. Research shows that when juvenile monkeys are socially isolated for the entirety of their childhood, cannot behave in a socially appropriate manner when introduced to a group (Lillard & Erisir, 2011). Similar effects can be found in human children.

For example, the neglect of children during their early critical period has been observed on a wide scale in Romanian orphanages. In 1966, the communist leader of Romania banned abortion and contraceptives and gave lavish rewards to parents who had multiple children. Unfortunately, this led to a mass abandonment of children. In the orphanages, "Romanian orphans, it is estimated, receive[d] five to six minutes of attention a day" (Perlez, 1996). Western reporters observed "children in cribs rocking back and forth as if they had autism…. [and] toddlers desperate for attention" (Hamilton, 2014). These children "whose early years were spent in extreme social deprivation in Romanian orphanages under Ceauşescu later suffered from attachment disorder. Cognitive impairments were also observed in some of these children, and the later children were adopted, the worse they fared, even controlling for years in the adoptive homes" (Lillard & Erisir, 2011).

While learning during this critical early period is vital, neuroplasticity continues throughout the rest of a person's life. Whereas neuroplasticity happens throughout all parts of the brain during childhood, it occurs in more specific regions and it is more nuanced later in life (Mora, 2013). While neurogenesis tends to stop in most parts of the adult brain, it continues in the hippocampus and the olfactory bulb (Lillard & Erisir, 2011). Large scale changes to the adult brain structure can still occur in many situations with the proper stimulus (Lillard & Erisir, 2011). A victim of the Romanian orphanages, Izidor Ruckel, would later describe in a memoir being a horrible child to his adoptive parents in California. However, while many of the children never recovered, and lived permanently scarred by their early neglect, he would later make peace with his parents and live a productive life. This recovery was in part because "his brain has changed," (Hamilton, 2014). Ruckel says, "I believe that even the brain cells that don't work as a child, I believe that they can develop as a grown man" (as cited in Hamilton, 2014).

Neuroplasticity in Disease, Addiction, and Stress

The adult brain is constantly presented with new challenges. Neuroplasticity plays an vital role in stroke treatment, spinal cord injury recovery, addiction, depression and stress. In some cases, neuroplasticity can be an asset, and in others, a liability.

Strokes

A stroke occurs when a part of the brain dies. This often occurs due to blood clots cutting off oxygen to parts of the brain. It is estimated that 55%-75% of stroke survivors have a reduced quality of life (Cramer, et al., 2011). After a stroke, the brain goes through a massive reorganization. Each stroke affects different parts of the brain and has different levels of severity. The motor region of the brain can be shut down, and these functions can move to a different part of the brain (Cramer, et al., 2011). Due to neuroplasticity, new neurons have been shown to branch out from undamaged parts of the brain, taking on new roles (Cramer, et al., 2011). In animal studies, rehabilitation has been shown to be the most effective in the short critical period after the stroke (Smith, 2013). Treatment options include "constraint-induced movement therapy for the arm and hand, body weight-supported treadmill training, robotic devices, [behavioral shaping], bilateral arm training and task-oriented physical therapy" (Cramer, et al., 2011). Success with these treatment options shows that neuroplasticity can be encouraged.

Spinal cord injuries

Spinal cord injuries (SCI) lead to a period of neuroplasticity not just in the brain but in the spinal cord. Paralyzed people cannot use the part of the body below the injury. Christopher Reeves, an actor who played Superman, was paralyzed from the neck down. Some treatments for SCI include exercising the affected limbs to encourage nerve growth (Cramer, et al., 2011). With neuroplasticity, it is believed that new nerves can grow back in the spinal cord, leading to a limited restoration of function.

While enhanced neuroplasticity is usually a good thing, in spinal cord injuries some kinds of neuroplasticity may be harmful. According to Weaver and Brown (2012), "examples of this are muscle spasticity, neuropathic pain, autonomic dysreflexia, urinary bladder dyssynergia, bowel dysfunction, cardiac arrhythmias and sexual dysfunction" (p. 134). Therefore, doctors must be careful on what type of neuroplasticity they want to encourage.

Addiction

Neuroplasticity also plays a role in addiction because the repeated use of addictive substances or behaviors can lead to changes in the brain. First, neuroplasticity is part of tolerance (O'Brien, 2009). Tolerance is shown through the "reduced effects from a given dose [of an addictive substance] that is given repeatedly" and physical dependence "is manifested by withdrawal symptoms when the drug is stopped abruptly" (O'Brien, 2009). The reason for tolerance and withdrawal is neuroplasticity. The second mechanism that addictive substances affect is the brains reward circuitry. Originally evolved to reinforce "adaptive behavior such as that leading to the acquisition of water, food, and sex. Drugs that directly activate the reward system may produce learning that diverts the individual to those behaviors that repeat the drug-induced feelings of reward" (O'Brien, 2009). This type of addiction tends to be "stable and perhaps permanent" because "the dopamine release caused by a drug of abuse tends to be greater than that of natural rewards, and to continue with repeated exposure rather than diminish, as is the case with natural, expected rewards" (O'Brien, 2009). Because addiction changes the wiring of the brain, relapse is possible even after years of abstinence (O'Brien, 2009). Because neuroplasticity is a major component of causing addiction, recovery also requires changes to the brain.

After a person chooses to stop the use of an addictive substance, "recovery involves a major change in thoughts and feelings, and such changes require ongoing neural development or neuroplasticity" (Lewis, 2015). When someone is addicted, "they can no longer separate their desire for well-being from their desire for drugs, booze, or whatever they rely on" (Lewis, 2015). Once the substance is removed, the brain is forced to rewire itself adapt to its new circumstances.

Therefore, "their brains begin to grow new synaptic patterns, allowing them to separate familiar goals (like drugs) from long-term rewards (like wellbeing and security)" (Lewis, 2015).

Depression and Stress

Depression and stress can hinder neuroplasticity. The prefrontal cortex and the hippocampus, tend to atrophy under severe stress (Davidson & McEwen, 2012). Decreasing the size of the prefrontal cortex leads to an "impairment of concentration and attention" (Pittenger & Duman, 2008). The hippocampus has a "clear role in declarative memory" and the "hippocampus and [prefrontal cortex] function cooperatively to regulate explicit memory" (Pittenger & Duman, 2008). This is consistent with the fact that depressed people tend to have impaired memory, and have difficulty focusing.

On the other hand, moderate to severe stress appears to increase the growth of the amygdala, the emotional center of the brain (Davidson & McEwen, 2012). Therefore, "chronic stress can enhance amygdala-dependent learning, in contrast to its effects on hippocampus-dependent declarative learning" (Pittenger & Duman, 2008). While a healthy individual might be able to accept criticism as constructive, a chronically stressed person might take criticism personally. This behavior may further someone's downward spiral of depression.One treatment of depression and chronic stress, antidepressants, work in part because they are able to encourage neuroplasticity (D'Sa & Duman, 2002). While the numerous types of antidepressants and their mechanisms go beyond the scope of this paper, it is believed that some antidepressants can modify gene expression and signaling pathways in the nervous system leading to less depression (D'Sa & Duman, 2002). Antidepressants cause adaptations "at the molecular and biochemical levels" and "chronic administration of antidepressants produces morphological changes in neurons [that] could explain how these drugs mediate persistent structural plasticity in the brain"

(D'Sa & Duman, 2002). Antidepressants are not the only treatments for depression that increase neuroplasticity. Non-medication related depression treatments also have an effect on neuroplasticity. Electric convulsive therapy (ECT) has "one with the most profound effects on the mechanisms of neuroplasticity" (Pittenger & Duman, 2008). Unfortunately, retrograde amnesia is an negative side effect of ECT (Pittenger & Duman, 2008). The less invasive, meditation training, has shown to make many changes in the brain including an increase white matter (Lillard & Erisir, 2011). Studies have also shown that meditation can increase the "gray-matter density in the hippocampus" and decrease "gray-matter density in the amygdala" (McGreevey, 2011). Cognitive behavioral therapy, a common form of talk therapy, has been shown to "simultaneously change… the physical structure and neurofunctional response of the amygdala" (Månsson, 2016). Further research could be done on additional forms of depression therapy.

It is important to note that mild stress, or eustress, can enhance neuroplasticity. Animals introduced to mild stress have shown decreased anxiety as adults (Davidson & McEwen, 2012). Mild stress can stimulate brain growth enhancing prefrontal cortex functioning (Davidson & McEwen, 2012). Ultimately, the proper management of stress can lead to significant brain changes.

Enhancing Neuroplasticity

While neuroplasticity is always happening, there are many things a person can do to enhance it. As mentioned in the previous section, antidepressants and mild stress can lead to increased brain growth. Exercise and enriched environments also have an effect on neuroplasticity.

In addition to the weight loss and the muscle gain benefits of exercise, aerobic exercise can lead to “increased neurogenesis and angiogenesis” (Cramer, et al., 2011). Exercise can release growth factors such as brain-derived neurotrophic factors that can lead to increased neuroplasticity (Cramer, et al., 2011). Adult mice experiments have shown a 25% increase in hippocampal neurons in active mice compared to sedentary mice (Lillard & Erisir, 2011). In human adults, “aerobic exercise program[s] lasting even just a few months significantly benefit cognitive functioning in both healthy ageing and early dementia, may be of benefit in schizophrenia, and have been shown to increase brain volume in a variety of regions and to enhance brain network functioning” (Cramer, et al., 2011). This research on neuroplasticity should give physicians have additional evidence to convince their patients to exercise.

Enriched environments also lead to increased neuronal growth. Mice put in cages with “conspecifics and ladders and bridges and burrows” outperformed those that lived in normal cages (Lillard & Erisir, 2011). An “experience in an enriched environment attenuates neuropathology, enhances neurogenesis, and facilitates synaptic plasticity” (Hu, et al., 2010). This can be applied to human environments. A way to help mitigate the negative effects of aging is to provide the elderly with projects and things they find intellectually stimulating (Cramer, et al., 2011). In short, an idol retirement might seem ideal, in the long run being engaged with projects and the community is a better way to live one’s twilight years.

Ultimately, “neuroplasticity is strongly amplified when people are highly motivated” (Lewis, 2015). While “passive exposure can bring neuroplastic change early in life,” in the elderly “paying attention is key to neuroplastic change (Lillard & Erisir, 2011). In the end to maximize the benefits of neuroplasticity, a person needs to be intentional about what they want to change and to put effort into it. Overcoming addiction is difficult, but not impossible to overcome. Learning disabilities might be hard to deal with, but with intensive support, a lot of hard work and under the right conditions, people can overcome them.

Conclusion

While research on neuroplasticity continues in this relatively new field, several conclusions can already be made. The brain is a constantly changing place contrary to previous beliefs. It is important to learn during the younger "critical" periods of life. Understanding neuroplasticity is a way to help treat neurological diseases. Depression and stress can hinder neuroplasticity while antidepressants and exercise can enhance it. It is an encouraging thought that while it might be very difficult, every mind can change. Further research on neuroplasticity will enhance our lives in the future.

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