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Neuroplasticity and Learning: The Relationship Between the Changing Structure of the Brain and Learning Processes

Abstract

Neuroplasticity refers to the brain's lifelong capacity for change and is central to learning processes. Thanks to neuroplasticity, connections between nerve cells can strengthen or weaken, new connections can form, and the brain can change structurally. These processes enable individuals to acquire new skills, store information, and adapt to various environmental demands. The purpose of this article is to examine in depth the relationship between neuroplasticity and learning, explain the biological mechanisms of neuroplastic changes, and discuss how this information can be integrated into educational and rehabilitation practices.

Additionally, age-related changes in neuroplasticity and its potential in the treatment of neurological disorders will be evaluated.

Keywords: *neuroplasticity, learning, brain, mechanism, ability, knowledge, skills*

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Neyroplastiklik və öyrənmə: beynin dəyişən strukturu ilə öyrənmə prosesləri Arasındakı əlaqə

Xülasə

Nevroplastiklik, beynin həyat boyu dəyişmək qabiliyyətini ifadə edir və öyrənmə proseslərinin mərkəzində dayanır. Nevroplastiklik sayəsində sinir hüceyrələri arasında əlaqələr möhkəmlənə və zəifləyə bilər, yeni əlaqələr formalaşa bilər və beyin struktural olaraq dəyişə bilər. Bu proseslər fərdlərin yeni bacarıqlar əldə etməsinə, məlumat saxlamağa və müxtəlif ətraf mühit tələblərinə uyğunlaşmağa imkan verir. Bu məqalənin məqsədi, nevroplastiklik və öyrənmə arasındakı əlaqəni dərindən araşdırmaq, nevroplastik dəyişikliklərin bioloji mexanizmlərini izah etmək və bu məlumatları təhsil və reabilitasiya praktikalarına necə daxil etmək barədə müzakirə etməkdir. Ayrıca, yaşla əlaqədar nevroplastik dəyişikliklər və nevroloji xəstəliklərin müalicəsindəki potensialı qiymətləndiriləcəkdir.

Açar sözlər: *nevroplastiklik, öyrənmə, beyin, mexanizm, qabiliyyət, bilik, bacarıqlar*

Introduction

The impetus for continual learning and updating of skills to adapt to new environments throughout the lifespan has increased to meet the demands of an aging population and agile workforce. This has encouraged many nations to embrace the culture of lifelong learning

(UNESCO, 2020). It is evident that adult learners embody unique neurobiological, socioemotional, and health-related lifestyle changes that are differentiated from children and adolescents. Indeed, early evidence distinguishing adult from childhood learning emerged through the work of educator Malcom Knowles. This work pioneered the distinction between pedagogy (i.e., methods of teaching children and adolescents) and the adult learning theory or the art of teaching adults, termed andragogy (Knowles, 1978). Adult learning theory outlines five key assumptions about the way in which adults learn, which are differentiated from children. These assumptions include self-concept and awareness, experience (prior knowledge), readiness to learn (need-to-know), orientation to learning (practical use), and intrinsic motivation to learn (see (Knowles, 1978) for review on adult learning theory).

Research

While these andragogical principals are grounded in psychological theories of how the adult brain learns, it is also plausible that they interact with the neuroscientific underpinnings of the brain's inherent ability to adapt to the environment and experience structurally and functionally, termed neuroplasticity (Pascual-Leone et al., 2005). It is now well-established that the adult brain has capacity for neuroplasticity over the entire lifespan (Draganski, 2006; Lövdén et al., 2013). Neuroplasticity can take form through any changes in neuron morphology (structure), rewiring of neuronal network connections, growth of new neurons (neurogenesis), and neuro- chemical /neurotransmitter adaptations (Pascual-Leone, 2005). However, advancements in non-invasive neuroimaging techniques, for example, structural and functional magnetic resonance imaging (MRI) have further provided evidence of brain network reorganization in humans.

To sustain learning and memory across the lifespan, neuroplasticity is required to recognize and strengthen synaptic connections among neurons (termed Hebbian plasticity) and also stabilize neural network activity (termed homeostatic plasticity) (Power & Schlaggar, 2017). Of particular importance to adult education and learning is that these structural, functional, and chemical adaptations can shape neuroplasticity in both a positive (i.e., desirable/beneficial) or negative (i.e., deterioration) direction, yielding differential outcomes on brain health, cognitive abilities, and learning. Fostering neuroplasticity in the positive direction requires insight into neurobiological and cognitive aging trajectories, along with the influence of socioemotional, environmental, and health-related lifestyle factors on brain health and cognition.

As an individual progresses through adulthood into later-life there is a natural age-related trajectory of decline in brain structure and function, as well as certain domains of cognition that may impact learning. However, research has shown that these neurobiological changes are not inevitable, are highly individualized, and can be modified through experiential and environmental factors (Phillips, 2017). For example, life course experiences such as continued education, social engagement, sociocultural knowledge, cognitive stimulation, physical activity, diet, and stress could all have a profound impact on how effectively the brain can compensate for age-related neurobiological changes over the lifespan and maintain cognitive functions pertinent for lifelong learning.

It is important that educators, business leaders, and adult learners themselves develop a rich understanding of age-related changes across different cognitive domains, to be aware of how learning policies and programs can be designed to account for adults'cognitive strengths while compensating for other domains that may begin to decline. From a broader perspective, nurturing social and physical learning environments that optimize brain health and compensate for natural age-related decline in brain structure and function can form a solid foundation for neuroplasticity and learning to occur. Designing effective learning policies that are grounded in these concepts could empower adult learners to maximize their learning opportunities and potential, within both formal and informal learning settings.

Therefore, the overall goal of this Chapter is to provide an overview of adult neuroplasticity from a holistic neurobiological, sociocultural, and brain health per- spective. We will consider findings evidenced in neuroscience research to foster neuroplasticity with factors of lifestyle and experiences that could impact learning in the adult life trajectory. This overview will assist the field of research in the science of adult learning to build a framework that aims to drive neuroplasticity in a positive direction and promote learning over the lifespan, allowing midlife and older adults to continue to positively contribute to the workforce and society.

What is Neuroplasticity?

Neuroplasticity is the brain's capacity to continue growing and evolving in response to life experiences. Plasticity is the capacity to be shaped, molded, or altered; neuroplasticity, then, is the ability for the brain to adapt or change over time, by creating new neurons and building new networks.Historically, scientists believed that the brain stopped growing after childhood. But current research shows that the brain is able to continue growing and changing throughout the lifespan, refining its architecture or shifting functions to different regions of the brain. The importance of neuroplasticity can't be overstated: It means that it is possible to change dysfunctional patterns of thinking and behaving and to develop new mindsets, new memories, new skills, and new abilities. Neuroplasticity encompasses how nerve cells adapt to circumstances–to respond to stimulation by generating new tendrils of connection to other nerve cells, called synapses, and to respond to deprivation and excess stress by weakening connections.Neuroplasticity underlies the capacity for learning and memory, and it enables mental and behavioral flexibility. Research has firmly established that the brain is a dynamic organ and can change its design throughout life, responding to experience by reorganizing connections – via so-called "wiring" and "rewiring." Scientists sometimes refer to the process of neuroplasticity as structural remodeling of the brain. The brain changes most rapidly in childhood, but it's now clear that the brain continues to develop throughout life. At any time, day-to-day behaviors can have measurable effects on brain structure and function. For example, a well-known study of British taxi drivers found that memorizing the city streets led to changes in the memory center, the hippocampus, and that those who had driven for longer had more expansion in the hippocampus. These changes in middle age highlight the role of neuroplasticity in learning across the life span. The ability of the brain to change and grow in response to experience enables people to bounce back from setbacks and adversity–to be resilient. They can bend without breaking. The disruption of neuroplasticity by severe stress or adversity is characteristic of such conditions as depression and post-traumatic stress disorder. There is quite literally a loss of synapses. In those disorders, people get stuck in neural ruts of negative thinking/feeling/behaving or fear-based memories. All psychotherapy is intended to foster resilience; the goal is to help people examine distressing feelings and experience and redirect them into more functional patterns, restoring cognitive and behavioral flexibility. Aging is thought to decrease resilience through the cumulative detrimental effects of stress on neuroplasticity. The dynamic capacity of the brain to rewire itself in response to experience makes a case for lifelong stimulation as a way to maintain optimal brain health and to decrease the risk of dementia and degenerative disorders like Alzheimer's disease.

The Relationship between Neuroplasticity and Learning

In order for our brain to become stronger and more adaptable, we must test it in new learning situations. That is, we must provoke our brain to constantly change – either through the study of themes or concepts or from experience, through which we learn and modify our behaviors. Learning is the ability to change behavior as a result of experience so that an individual can adapt to new environmental and social situations. Hence, a learning process causes changes in a person at the cognitive, behavioral, and anatomo-physiological levels of the nervous system. Therefore, memory and learning are essential for the development of neuroplasticity, which is an intrinsic process of the brain. When we learn, we memorize and store information; this is a process that occurs in neural networks. With it, when we learn through study or experience, we stimulate our brain and allow two basic processes to take place:

- Sensory stimulation
- Cognitive stimulation

The vast majority of our brain contains only neurons that have been present since our birth; however, one small but very important area of our brain continues to grow new neurons throughout all of our life, through a process known as neurogenesis. This area is called the hippocampus and is known to play a crucial role in memory and learning. It is only in the last decade that researchers have shown that new neurons are born in the hippocampus in the human brain throughout life. In the most conclusive study, researchers used a carbon-dating technique to accurately determine the age of individual cells within the hippocampus. They estimated that around 700 new neurons are added to each hippocampus (left and right) every day, and by the time we are 60 years old about one-third of the neurons in our hippocampus will be new neurons formed by neurogenesis after birth. This has caused much excitement and is a topic currently at the forefront of research in neuroscience, but there is still a lot we do not know. For example, research only indicates the potential role of the new neurons in the hippocampus in learning or memory. We know that the hippocampus overall is crucial for laying down new memories, because people with damage to their hippocampus suffer severe amnesia and cannot remember anything after the time of the damage. We also know that the hippocampus plays a role in spatial navigation, or our ability to remember and “feel” our way around a familiar place, a discovery that led to award of the Nobel Prize in 2014 (https://www.news- medical.net/health/Hippocampus-Functions.aspx). We know many things that can boost neurogenesis, such as exercise, diet, reducing stress, and learning itself. There are now many books, internet sites, and emerging products advising how to enhance neurogenesis and thereby “boost your brain”. However, in truth we do not know whether specifically targeting neurogenesis is necessary or even beneficial for cognition, memory, or learning and so there is not enough evidence to claim that any of these things will actually “boost your brain”.

What we know is that the hippocampus continues to grow new neurons throughout life and that the hippocampus is crucial for learning and memory. But will enhancing the growth of new neurons in your hippocampus make you smarter? That is for future research to tell.

Neuroplasticity in Action

The brain has an incredible capacity to reorganise itself through rewiring, altering, and strengthening the connections and pathways that are used often. Just as Donald Hebb described, those pathways of interconnected neurons that are trained or used frequently, firing together, strengthen their connections and thereby wire together. Most research on large-scale brain changes with neuroplasticity focuses on how the brain recovers or reorganises following damage or injury. For example, the parts of our brain that control our body movements and our sense of touch have a kind of map of the body, known as a homunculus, so that neurons in a particular area connect to muscles in a specific part of the body. If someone has damage to this motor area of their brain, for example caused by a stroke or blockage of blood supply, then they will have severe weakness with movements of the part of their body corresponding to the part of their brain that is damaged. As we know, damaged neurons do not heal or regenerate and new neurons never grow in this part of the brain, but nonetheless people can regain control of their movements. With rehabilitation and repeated training of the weak movements, undamaged areas of the brain can remap their connections to take over function from the damaged areas. This is the basis of physiotherapy for movement rehabilitation, creating and strengthening new pathways as the brain relearns to control movement through new connections. The principles of creating and strengthening connections to mould the brain can also be applied to normal learning, not just the relearning involved following brain damage. For example, an interesting study showed that people who play string instruments actually have a larger region of the sensory area of their brain devoted to touch sensation of their left hand when compared with their right hand or compared with people who do not play string instruments. It seems that their extensive practice with finger movements on the strings with their left hand moulds their brain, creating and strengthening connections, so that more of the sensory area of their brain area is connected to their left hand. In another study, when a group of young adults were taught to juggle and practiced for three months, a particular part of the grey matter of their brain increased in size, in an area important for the perception of moving objects. When they stopped juggling and were examined after another three months, that area had returned back to its original size. We know that new neurons do not grow in that part of the brain, so the increase in size is not from the brain growing new neurons. A subsequent study showed that connections into the brain’s grey matter changed as people learnt to juggle, suggesting that practice and use of the skill enhances brain connections. The brain therefore has an enormous potential to adapt and change by altering and strengthening connections through use and experience. The use of particular brain pathways strengthens those pathways. This is thought to be the major way that the brain learns, by adapting and changing connections with experience.

Evidence for Structural and Functional Neuroplasticity in Adults

The lifelong potential of the adult brain to undergo structural and functional reorganisation is now well established (Tardif, 2016). These changes have also been associated with skill acquisition (Sagi, 2012) and maintenance of cognitive capacities (Shaffer, 2016), providing strong support for the relationship between neuroplasticity and learning throughout adulthood. While early evidence for adult neuroplasticity emerged from animal studies (Lövdén, 2013), rapidly advancing methodologies in non-invasive neuroimaging such as magnetic resonance imaging (MRI) have provided insights into the functional and structural properties of the living human brain consistent with neurobiological changes supporting inferences for neuroplasticity (Tardif, 2016). Indices of structural neuroplasticity which can be measured through MRI include changes in grey matter (density of neurons) and white matter (axonal connections between neurons) volumes and white matter connectivity. Measures of functional neuroplasticity include changes in the metabolic responses (activations) of specific brain regions or groups of regions (connectivity) either at rest or while performing a task. Both structural (Draganski, 2006) and functional (Gurunandan, Carreiras, & Paz-Alonso, 2019) neuroim-aging changes have been shown to be correlated with learning and memory in adults and provide pivotal evidence of how the adult brain adapts to experience, training, and the environment.

The relationship between neuroplasticity and learning is evident from early childhood and neurodevelopmental research into sensitive periods, where the association between structural reorganization, functional properties, and behaviors are robust (Knudsen, 2004). This is thought to be due to higher malleability of the synapses (connections between neurons) among immature neurons (Martin, Grimwood, & Morris, 2000). As fundamental cognitive and motor functions (e.g., hearing, vision, motor skills, and emotional regulation) are developed and consoli- dated throughout childhood and adolescence, these synaptic pathways are strengthened, and irrelevant pathways not used are "pruned". However, the notion that the brain becomes fixed outside of these sensitive periods has now been debunked by a growing body of evidence demonstrating the capacity for neuroplasticity in adult- hood and into later-life (Spalding, 2013). One example of this is the observation of neurogenesis occurring in the adult hippocampus, a brain region implicated in learning and memory (Spalding, 2013). Importantly, this has been shown to occur at a rate and magnitude great enough to have a positive impact on human cognition and behavior (Spalding, 2013).

In human studies, neuroimaging research supporting neuroplasticity in the adult brain has been conducted to examine structural and functional adaptations between experts and novices across various occupations (Wu, 2020). One of the famous examples of experiential neuroplasticity comes from studying London taxi drivers, whereby the number of years (i.e., expertise) spent driving taxis and navigating complex street maps correlated to the grey matter volume of the posterior hippo-campus, which is associated with procedural learning and spatial memory (Maguire, 2000). Changes in structural and functional neuroplasticity have further been observed in experts compared with novices in occupations such as dancers and musicians (Gujing et al., 2018), mathematicians (Popescu, 2019), writers, pilots, and athletes (Wu, 2020). This provides evidence that building expertise through training and practice can alter the structure and function of the adult brain.

In addition to expertise, evidence of structural and functional reorganization has been shown to underpin the acquisition of a range of cognitive, motor, and literacy skills (Bubbico, 2019; Dayan & Cohen, 2011; Draganski, 2004). For example, compared with monolingual adults, bilingualism has shown to be protec- tive against cognitive decline (Grundy, Anderson, & Bialystok, 2017), and learning a new language in adulthood can induce functional reorganization within language-specific brain regions, regardless of age (Bubbico, 2019). Collectively, this evidence strongly supports the capacity of the adult brain to undergo neuroplasticity across the lifespan, with subsequent positive effects on learning.

Directions for Future Research and Application

While the trajectory of neuroplasticity and cognition over the lifespan is malleable, variable, and influenced by modifiable lifestyle factors, the direct relationship between these factors and lifelong learning remains to be comprehensively examined. Future longitudinal and intervention research examining the relationship of neuroplasticity and real-world learning outcomes in adults will be important for the future development of programs, policies, and awareness initiatives promoting brain heath and neuroplasticity for lifelong learning. Given factors such as sleep, dietary patterns, and exercise constitute part of a healthy lifestyle and appear to promote brain health via complementary and cumulative effects on the brain's architecture and function, lifestyle modification should be considered holistically in educational and workplace policies that could promote neuroplasticity for enhancing adult learning.

While the evidence we have reviewed suggests a strong capability for the adult brain to undergo neuroplasticity, much of what we have learned about neuroplasticity and its subsequent effects on learning and memory has been derived from models of aging and cognitive decline or dementia. There is still limited research on healthy adults in middle-age which has been proposed as a critical window for modifiable changes in the pursuit of preventing age-related neurodegeneration and disease. It is important for future research to enhance the understanding of brain health and learning in this stage of life to maximize human potential. This is because midlife encompasses an important phase of work productivity and change in the human lifespan where much learning of new skills to adapt to the ever-changing environments are happening. To have greater impact on society, adult education and lifelong learning policies, further research in this area is encouraged to elucidate whether promoting neuroplasticity in midlife has subsequent effects on ecological adult learning outcomes such as skills development and job performance.

Conclusion

In summary, the capacity for the adult brain to undergo neuroplasticity and acquire new skills is well documented, and this adult learning is experience dependent.

Several factors pertaining to an adult's environment and health can influence the flexibility of the brain to adapt and adjust over the lifespan to maintain and improve cognitive skills. Therefore, in addition to the andragogical principles of adult learning, the consideration of the neurobiological, socioemotional, and health- related lifestyle influences on neuroplasticity across the lifespan could empower adult learners to maximize their brain heath, learning, and societal potential.

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