Educational Administration: Theory and Practice
2024, 30(11), 511 - 517
ISSN: 2148-2403
https://kuey.net/

Research Article

Neuroplasticity And Adult Learning: Can An Old Dog Learn New Tricks?

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Citation: Andriana Eliadis, (2024), Neuroplasticity And Adult Learning: Can An Old Dog Learn New Tricks? *Educational Administration: Theory and Practice*, 30(11) 511 - 517
Doi: 10.53555/kuey.v30i11.8640

ARTICLE INFO

ABSTRACT

Adult learning has always remained a topic of discussion among researchers. Thus, this study aimed to extend this debate in the context of literature. This is a qualitative literature-based review that has focused on prior studies. Following the comprehensive inclusion and exclusion criteria, the data was gathered from academic journals and books. The results reported a strong connection between neuroplasticity and adult learning. They negated the old dogma that the brain's cells never regenerate, and adults cannot learn as effectively as when they were young. The findings highlighted that adults taking a healthy and nutritional diet and exercising regularly can learn as effectively as the younger ones do as their brain cells can regenerate. This research has focused on all the available literature, but future studies may extend it by focusing on the latest studies. Further, they can empirically differentiate the learning abilities of young and adult individuals.

Keywords: Neuroscience, Neuroplasticity, Adult Learning, Neurons, Learning, Hypothalamus

INTRODUCTION

Learning is about biology -only living things learn, as there is a natural connection between brain structure and learning (Zull, 2002). It is considered a phenomenon in which the brain captures information from the external environment, retains it for some time, and uses it to orient subsequent behavior. Learning is often overlapped with memory, but memory is a whole process, and learning is merely its acquisition stage. Learning becomes a reciprocal exchange when interaction between brains occurs. In this exchange, two brains learn simultaneously; thus, reciprocal learning is considered the most critical process that enables humans to progress materially or build a mental improvement (Tovar-Moll & Lent, 2016). We learn many things in our daily lives, and this learning has different forms (Meltzoff et al., 2009), ranging from observation of simple still objects to highly complex things such as playing musical instruments (e.g., orchestra). Toddlers can learn simple things, but when they discover the best learning strategies, they start learning complex and exciting things. Thus, they learn to learn (Tovar-Moll & Lent, 2016).

The term “neuronal plasticity” was coined by Santiago Ramon y Cajal (1852-1934), who first explained the nonpathological changes in the brains of adults. This term originated the controversial discussion because many neuropathologists supported an old dogma that there is a fixed quantity of neurons in an adult’s brain (Stagnisch & Nitsch, 2002). Zilles (1992) explained the brain’s plasticity more comprehensively as “the ability to make adaptive changes related to the structure and function of the nervous system” (p. 383). Therefore, “neuronal plasticity” not merely encompasses the morphological variations in brain regions and modifications in neuronal networks, including changes in connection and the production of new neurons (neurogenesis). However, it also represents neurobiochemical transformations (Fuchs & Flügge, 2014). Tovar-Moll and Lent (2016) explained neuroplasticity as the biological mechanisms that enable a brain to receive, encode, store, and retrieve mutually exchanged information. Further, they defined it as “the ability of the brain to undergo temporary or permanent changes whenever it is influenced by other brains and by the environment” (p. 200). Neuroplasticity is associated with competitiveness; if we cease to engage our cognitive abilities, we forget them, and the relevant neural pathways are reallocated to other processes we continue to perform. We may modify the phrase "learn a trade for a rainy day" to "learn a trade for ever” day and continue to practice it regularly" (Guglielman, 2012, p. 200).

In 1928, Edward L. Thorndike, in his book *Adult Learning,* which was not related to adult learning modes, explored adults' capability to learn. This was important because it revealed a scientific basis that adults "can" learn, which was only based on faith in the past. Additional research on Thorndile's discovery of adult ability to learn was conducted in 1938 by Herbert Sorenson in *Adult Abilities* (Knowles et al., 2005). The learning capabilities vary for each adult, and the distinct characteristics of adults as learners necessitate formulating pedagogical tactics and approaches tailored to their individual needs. Moreover, they identify the components and variables that must be monitored to enhance the efficacy of training interventions. Many studies on adult education and the domain of geragogy focused on characterizing learning with the maturity of age (Guglielman, 2004; 2005; Johnson & Taylor, 2006; Grady, 2012; Knowland & Thomas, 2014; Merideth, 2021). However, recent work on learning and brain development suggested that adult learning and educational experts need to increase their knowledge in neuroscience and the adult brain to help develop an environment that facilitates brain development. The brain is a social organ inherently structured to acquire knowledge through collective experiences (Cozolino & Sprokay, 2011). Learning at a mature age can be problematic as aging brain tissues may cause mind inefficiency. Some studies on neuroplasticity confirmed that adult learning can be successful if the brain is engaged in challenging and complex tasks or activities. Therefore, learning is linked to neuroplasticity as it allows the retention, processing, and representation of new information (Guglielman, 2012).

A human brain is a learning machine. The brain learns in many ways and under many circumstances, including in the classroom, thanks to neuroplasticity. Brain plasticity or neuroplasticity refers to "changes in the structure and function of the brain that result from the interaction between the brain and its environment" (Cavanaugh & Blanchard-Fields, 2017, p. 49). There are two main types of brain plasticity: a. Functional- which refers to neural activity and connectivity and how it changes in response to specific events and/or experiences. For example, activity may increase in some brain regions after an injury to compensate for lost functions. B. Structural-new information and/or experiences. For instance, learning a new language or taking music lessons can change the brain's physical structure, making certain areas increase or decrease in size (Vandergriendt, 2022). Thus, neuroplasticity is the brain's ability to rewire itself and, in that way, remain sharp. Neurogenesis is the formation of new neurons, a central part of brain plasticity (Vandergriendt, 2022). As technology continues to evolve, and through fMRIs and other technological devices, researchers have found compelling factors about the human brain and its ability to grow, learn, and form new neurons and connections. The relationship between education and neuroscience, the new emerging NeuroLeaderhip, and NeuroCoaching offer intriguing possibilities for research and practice. As these new domains advance, it is wise to coach researchers, educators, and practitioners to be well-acquainted with their literature (Bachkirova et al., 2017).

Many studies have focused on examining the adult brain's capacity for adaptation in response to experience (i.e., known as neuroplasticity) is extensively recognized. However, there needs to be more research highlighting the capacity in which neuroplasticity or learning over the lifespan is influenced by an individual's life experiences or aging trajectory. Nowadays, the developments in non-invasive human neuroimaging have made it possible to quantify the neurobiological mechanisms that drive cognitive trajectories over the lifespan. Moreover, this has led to a more in-depth understanding of various concepts, including cognitive and brain reserve, brain compensation, and resilience (Chen & Goodwill, 2022). Until recently, scientists thought that neurogenesis was constrained to early brain development; however, in the last decades, numerous findings have challenged this view and have shown the birth of new neurons in the adult brain, particularly in areas associated with learning, such as the hippocampus (Amthor, 2016). Thus, the central question of this paper is: What is the connection between neuroplasticity and adult learning? Can an "old dog" learn new tricks?

LITERATURE REVIEW

Neuroplasticity and Adult Learning

Gage (2019) confirmed that new neurons are generated in the adult rat hippocampus, which is important for learning and memory. Intriguingly, new neurons increase in number in the hippocampus if the animal is exposed to an enriched environment with toys and playmates. Moreover, when the rats regularly run on an exercise wheel, they show enhanced neurogenesis (Bear et al., 2016). Similarly, Suzuki (2017), in her TED Talk on the benefits of physical exercise for the brain, claimed that the most transformative outcome of exercise is its protective effects on one's brain. The brain is like a muscle. The more one works it out, the bigger and stronger the hippocampus and prefrontal cortex gets. She asserted its importance as the prefrontal cortex and the hippocampus are the two most susceptible to neurodegenerative diseases and average cognitive decline in aging. Thus, increased exercise over one's lifetime will create a more robust and bigger hippocampus and prefrontal cortex, which can delay possible dementia or Alzheimer's diseases (Suzuki, 2017).

Furthermore, Spalding et al. (2005) took the concepts underlying radiocarbon-dating techniques used in archaeology and developed an ingenious strategy to discover the carbon dating in the neurons of human postmortem brains, which were exposed to radioactivity due to hundreds of nuclear bombs that were detonated for testing purposes in the years between 1955 and 1963, causing radioactive contagion. During this period, there was a spike in the environmental levels of the radioactive isotope of carbon, 14C, which was absorbed into the biological molecules of all living things, including the replicating DNA of human neurons. This radioactivity put a time stamp on every cell born during the bomb pulse (Spalding et al., 2005). The neocortex neurons were

the same age as the individual; thus, no new cells had been generated. However, as seen in Figure 2, the data showed that hippocampal neurons were continuously generated across their lifecycle. The researchers calculated that "700 new neurons were added to the hippocampus every day" (Kheirbek & Hen, 2013, p. 1183). This number was about equal to the neurons lost, thus keeping the total number of hippocampal cells about constant. "The annual turnover rate is 1.75%, similar to the levels found in middle-aged rodents" (Kheirbek & Hen, 2013, p. 1183). This research is of great significance as it can further study the contribution of adult hippocampal neurogenesis to improving human behavior and mental health problems. Consequently, the hippocampus does generate neurogenesis. In all the cases above, neurogenesis correlates with enhanced performance on memory tasks that require the hippocampus.

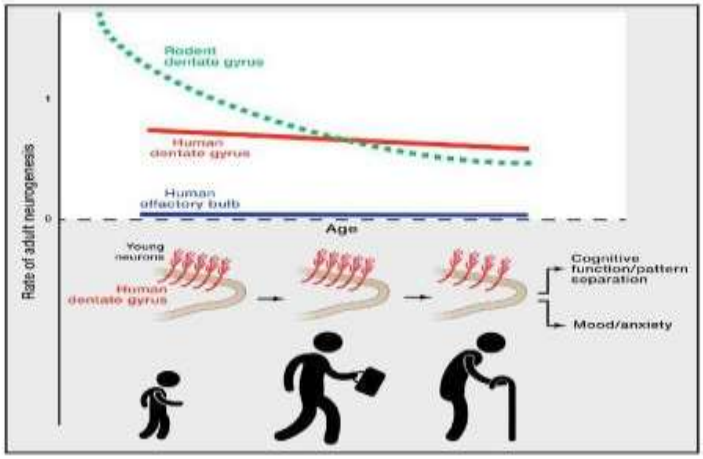

Figure 1: Comparative Rates in Adult Neurogenesis in Rodents and Humans
Source: (Kheirbek & Hen, 2013)

**Although a superficial level of adult neurogenesis is reported in the human olfactory bulb (blue line), the human hippocampus continues to generate neurons at a steady rate well into old age, with only a modest decline throughout adulthood (red line). The rate of neurogenesis in adult humans is comparable to levels seen in middle-aged rodents (9 months old; intersection of the green line and red line). These results suggest that rodent studies revealing the role of adult hippocampal neurogenesis in cognitive function (pattern separation) and emotional behavior (mood/anxiety) may also hold true in adult humans.*

Neurons are not physically attached via the synaptic process, and they have the flexibility to create, break, and recreate links with other neurons (Sweeney, 2009); thus, learning and memory can occur at synapses. Many fundamental mechanisms seem universal regardless of species, brain location, and memory type. Events are characterized initially as changes in the brain's electrical activity, then as intracellular second messengers, and subsequently as alterations of the present synaptic proteins (Bear et al., 2016). By changing the structure of the synapse, these temporary alterations become permanent and long-term memories. In many forms of memory, this involves new protein synthesis and new microcircuit assembly. In other forms of memory, existing circuits may be disassembled.
Nonetheless, learning necessitates many of the same neurogenesis mechanisms used during the initial development to refine brain circuitry. One universal feature is the association of calcium, "Ca2+" (Bear et al., 2016, p. 897). Ca2+ is critical for neurotransmitter secretion and muscle contraction and is involved in almost all forms of synaptic plasticity. As Ca2+ is a charge-carrying ion and a potent second messenger substance, it has a unique capacity to directly connect electrical activity with long-term changes in the brain (Bear et al., 2016).

Adult Hippocampal Neurogenesis

Contrary to the earlier belief that new neurons are not formed in adults, adult neurogenesis has been widely examined through studies on rodents, and with varied hypotheses being tested, it can be concluded that numerous pathways are involved in adult neurogenesis. However, a decline in precursor cell generation has been observed during aging, and three hypotheses are actively being tested,

- The pool of stem cells in the hippocampus depletes with age
- The microenvironment changes with age, and it lacks the molecular cues required for the further creation of neurons
- The stem cells become less responsive with age

Eriksson et al. (1998) demonstrated that new neuron genesis occur in the human brain throughout life. Neurogenesis primarily occurs in two brain areas: the sub-ventricular zone (SVZ) of the lateral ventricles and the sub-granular zone (SGZ) in the hippocampus. The hippocampus is one of the few areas that generate new neurons throughout life. 50-80 percent of precursor cells in the sub-granular zone can mature into neurons

that migrate to the appropriate cell layer and form connections with other neurons. The hippocampus, being at the prime position in the brain, influences and is influenced by areas associated with mood and cognition (Eriksson et al., 1998; Kheirbek & Hen, 2013; Vandergriendt, 2022).
Moreover, Encinas et al. (2011) discussed and displayed hippocampal neurogenesis (Figure 2) and showed that with increasing age, a large number of astrocytes are generated from the activation of dormant neural stem cells. Moreover, individual neural stem cells go through the activation process, return to dormancy, and reactivate with limited depletion via astrocytic transformation (Bonaguidi et al., 2011). Adult neurogenesis is mainly activated by various brain injuries and by generating new neurons that migrate along the blood vessels toward the injured area, where they may repair the damaged tissue (Kojima et al., 2010; Marchetti et al., 2020; Yamashita et al., 2006).

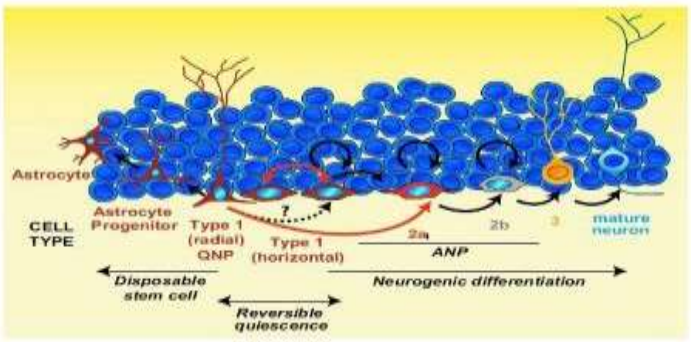

Figure 2: Schematic View of Hippocampal Neurogenesis
Source: (Encinas et al., 2011, p. 465)

**Two populations of putative stem cells (radial and horizontal type-1, brown cells) are primarily quiescent but transiently enter mitosis (red arrows) and generate the downstream neural lineage of committed progenitors (type-2a), mitotic neuroblasts (type-2b, gray), postmitotic neuroblasts (type-3, gold), and eventually, neurons (blue). Encinas et al. (2011) find that mitotic type-2 cells can be classed as active neural progenitors (ANPs). The authors propose a "disposable stem cell" theory, in which radial type-1 stem cells (termed QNPs, or "quiescent neural progenitors") divide very infrequently but, in doing so, differentiate into astrocytes, thereby depleting the stem cell pool. Whether radial type-1 cells generate horizontal stem cells or vice versa remains to be shown (dashed arrow) (Encinas et al., 2011, p. 465).*

It is essential to recognize that there are limitations to plasticity in the adult brain. Significant changes in brain circuitry generally occur during the critical early life periods. The growth and retraction of most axons in the adult central nervous system (CNS) are restricted to a few tens of micrometers (Bear et al., 2016). However, it is now evident that the end of that critical period does not necessarily denote an end to changes in the brain, as a physically and mentally stimulating environment can stimulate neuroplasticity and hippocampal neurogenesis even in adults (Marchetti et al., 2020).

Neuroscience and Adult Learning as an Integrative System

Neuroscience and adult learning are interdisciplinary fields that combine epistemological foundations and concepts from neuroscience, biology, psychology, education, and sociology. The concepts of neuroscience and adult education encompass the systemic operation of these complex systems working together holistically. Thus, neuroscience and adult learning cooperate as separate entities to create a greater whole. According to the concept of emergence (Bar-Yam, 2011), the outcomes of complex systems cannot descend from the characteristics of the competent alone. Hence, as traditionally known, the whole is greater than the sum of its parts; as stated, "the properties of the parts cannot be understood except in their context in the whole" (Bello-Morales, 2015, p. 2). Taking this concept to neuroscience, the brain is a complex system, a whole mechanism composed of its individual parts, working together as differentiated areas that link their neurochemical processes to create a holistic functional system. Although some linear aspects of brain function endure, like the tasks of the neurons and their firing through neurotransmitter release, the overall output of the brain is like a "spider web of interconnected processes" (Siegel, 2012, pp. 15-2). Adult learning triggers the brain's neuroplasticity and creates new pathways to change and learning. Consequently, brain functionality is part of adult learning (Aron & Aron, 1989).

METHODOLOGY

The advancement in neuroscience has highlighted that learning is not confined to younger individuals, but individuals of all age groups can learn. Moreover, continuous learning and solving complex problems can increase the regeneration of neurons (Guglielman, 2012). However, many researchers rely on an old dogma

that the brain has a limited number of neurons that never regenerate. Therefore, this research highlighted the literature focusing on neuroplasticity and adult learning. The most important thing while developing a literature analysis is considering the inclusion and exclusion criteria. This literature-based research has focused on all the aspects of inclusion and exclusion while scrutinizing the studies. To design an adequate strategy for scrapping the data, the articles published in high-quality journals were analyzed, and besides this, an expert opinion was taken to develop a comprehensive plan for defining the inclusion and exclusion criteria. According to the plan, the data was gathered from reliable data sources. Only highly quality articles published in reputed journals were considered. Moreover, the articles published in languages other than English were not shortlisted. Furthermore, in terms of theme, the studies focusing on neuroplasticity and learning, neuroplasticity and adult learning, adult learning and neuroscience, adult learning and neurons, and adults' brain regeneration, were considered. The inclusion and exclusion criteria are shown in Table 1 below.

Inclusion Criteria	
Factors	**Criteria**
Articles	Quantitative and Qualitative
Language	English
Themes	Neuroplasticity, Neuroplasticity and Learning, Neuroplasticity and Adult Learning, Adult Learning and Neuroscience, Adult Learning and Neurons, and Adults' Brain Regeneration
Exclusion Criteria	
Articles	Review papers, Conceptual Articles, Systematic Reviews, and Editorials
Language	Other than English Language

RESULTS AND DISCUSSION

This literature-based research has highlighted the connection between neuroplasticity and adult learning to understand whether adults can learn. It has also focused on adult hippocampal neurogenesis, neuroscience, and adult learning as an integrative system to support the argument. The results highlighted that studies have confirmed that brain cells can regenerate; thus, adults can learn and have learning capabilities equal to those of young ones. These findings align with the research by Cavanaugh and Blanchard-Fields (2017), who highlighted that although the human brain loses neurons as it ages, neuroplasticity gives it the power to form new connections, increasing the brain's complexity. Hence, when the brain encounters new, challenging educational experiences, it creates new synaptic connections. New synaptic connections can be formed at all ages, which explains how aging brains can compensate. Recent discoveries show that brain cells can regenerate, and brain plasticity can help people cope with age-related changes in the brain.
Similarly, Intlekofer and Cotman (2013) argued that aerobic exercise can enhance brain plasticity and preserve the size of the hippocampus, an area associated with memory. In addition, Cavanaugh and Blanchard-Fields (2017) reported that diets rich in vitamins in the B complex, C, D, E, and omega-3 fatty acids have been linked to better cognitive functioning and greater brain volume. Therefore, while the life expectancy in the United States has increased from 47.3 years in 1900 to 78.6 years in 2016, although racial disparities in health care affect longevity for African Americans, the human life span remains at approximately 110 to 120 years (Merriam & Baumgartner, 2020), regardless of race, changes in vision, hearing, and reaction time are inevitable within the aging process. However, new technologies such as cochlear implants and laser surgery for cataracts help older adults remain active and continue learning well into old age. In addition, researchers have learned more about the brain's elasticity. Older adults with deficits in one brain area may compensate for it in other areas (Merriam & Baumgartner, 2020).

Sweeney (2009) stated that experimental data with laboratory animals demonstrated the principle of "use it or lose it" (p. 13). She placed lab animals in a setting with challenging tasks and toys and observed that their brains developed a far greater number of neuronal networks than the animals raised in a dull environment. Therefore, "mental exercise can induce brain growth" (Costandi, 2016, p. 54). When the human brain is challenged via new learnings, it often arrives at a sudden "aha" moment. That is when various thoughts, not linked before, come together to form a new idea. This is the moment of a new neuro-path, a new neuro-connection. When this new circuit is formed, much energy is released, and people are motivated to action. That moment is a breakthrough, one discovering the solution to a problem. This is just like when the ancient Greek mathematician Archimedes, as he was taking a bath, discovered the method for determining the volume of an object with an irregular shape. From his excitement, Archimedes leaped out of his bath and ran out into the streets naked, shouting "*Εύρηκα*" ("Eureka"), which means "I found it." Such is how insights can impact humans (Bendick, 2001; Rock, 2006). Therefore, adults with an enriched diet and aerobic exercises can have better learning capabilities as these factors enhance the brain's plasticity and preserve the size of the hippocampus.

CONCLUSION

Neuroscience and learning share the joint mission of improving human capacities and bringing about development. Neuroscience provides a path to the biological level of behavior and health. Knowledge about the distinctive functions of the brain enables individuals to gain ample distance from the problematic situation to acquire a clear understanding and empathy for the challenging situation, the people involved, and themselves (Siegel, 2010). The discovery of neural stem cells proved erroneous the enduring conviction that neurogenesis dwindles away at the end of embryonic development. This means one can teach an old dog new tricks (Cavanaugh et al., 2017). Thus, the old saying goes down the drain!

IMPLICATIONS

Since the last few decades, there has been a debate on adult learning, and many researchers have presented their different views. Similarly, this research has contributed to this debate and highlighted that adults can learn and that there is a strong connection between neuroplasticity and adult learning. Moreover, it has extended the literature on adult learning, neuroplasticity, and brain regeneration. This research differs from prior studies that mainly focused on quantitative analysis or conducted experiments; as it has only focused on the prior literature by setting the inclusion and exclusion criteria. The findings of this research can be helpful for researchers focusing on adult learning. Moreover, it can be beneficial for adult educational institutions.

LIMITATIONS AND RECOMMENDATIONS

This literature-based research has presented a clear narrative on adult learning. However, it has several limitations that future studies can consider. First, it has focused on the available literature without setting any specific timeline, but future studies may extend this research by considering the latest articles. Secondly, this research has mainly emphasized adult learning, but further research is needed to differentiate the learning abilities of young and adult individuals.

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