# Neuroplasticity beyond the first years of life

Author/s:

**Julia Hermida**
*Professor, Institute of Education at the National University of Hurlingham (Universidad Nacional de Hurlingham -UNAHUR-), and a researcher at the National Council of Scientific and Technical Research, Argentina.*

Theme/s:

**Effective lifelong learning / Future of education and learning / Quality, equity, and relevance of education and learning**

This report arises from Science of Learning Fellowships funded by the International Brain Research Organization (IBRO) in partnership with the International Bureau of Education (IBE) of the United Nations Educational, Scientific and Cultural Organization (UNESCO). The IBRO/IBE-UNESCO Science of Learning Fellowship aims to support and translate key neuroscience research on learning and the brain to educators, policy makers, and governments.

## Executive Summary

The first three years of life are a period of considerable plasticity. This brief will summarize evidence of plasticity beyond 3.

Experience-dependent plasticity and reflects brain changes resulting from individual learning experiences. Experience-expectant plasticity and reflects brain changes common to most humans.

Both types of plasticity are observed after 3 years, even into old age.

The early years are very important, but subsequent years are important, too. There is room for learning, even in elderly people.

## Introduction

There is ample evidence that the first three years of life are an important time period in child development, characterized by plasticity in the developing brain (https://solportal.ibe-unesco.org/articles/is-there-really-a-better-age-to-start-school/). Evidence has shown that children exposed to adversity early in life are at increased risk for atypical variations in brain development and a variety of psychological, behavioral, and physical health negative outcomes[1]. Although exposure to adversity can happen at any point in the lifespan, exposure in the early years (0 to 3 years of age) seems particularly impactful on development[2]. For that reason, it has been claimed that the early years are a *sensitive period* in development (https://solportal.ibe-unesco.org/articles/brain-development-and-its-derangements/). In other words, the first three years of life are a timepoint in development during which plasticity (i.e., brain modification according to experience, https://solportal.ibe-unesco.org/articles/neuroplasticity-how-the-brain-changes-with-learning/) is considerable for some functions. But what happens beyond the early years?

## Evidence of plasticity beyond the early years: childhood and adolescence

To answer this question, it is useful to consider a key concept regarding plasticity: it comes in different forms (for example, see https://solportal.ibe-unesco.org/articles/the-plastic-brain/). One form is called experience-dependent plasticity and reflects brain changes resulting from individual learning experiences. Another form is called experience-expectant plasticity and reflects brain changes common to most humans.

Regarding experience-expectant plasticity, neuroscience studies have shown that brain development continues across the first two decades of life[3]. The human brain continues to develop during childhood and across adolescence and only reaches a "mature state" at the beginning of adulthood. How do we know this? For example, in one study[4], structural brain changes between 8 and 30 years were measured in 391 people from varied populations (from Norway, the Netherlands, and the United States) using magnetic resonance imaging (MRI) of the same people at different ages. There was evidence of structural brain changes with age, including into the third decade of life, showing continued development until adulthood. Structural changes beyond infancy–in fact, changes until 90 years of age–have been observed in various studies (see [5-7] for reviews). Although those studies cannot tell us what behavioral changes are associated with the structural brain changes, they are telling us an important message: Neuroplasticity does not end after 3 years.

But even "reaching maturity" through experience-expectant plasticity does not imply immutability; it just means acquiring a brain structural and functional advanced development. At the same time that the brain is maturing, developing children are having all sorts of individualized interactions with their environments (experience-dependent plasticity). For example, some are learning fractions, some are taking gymnastics, and some are taking care of younger siblings. Education is a rich and varied experience for human development, so it is notable that there are also many studies showing experience-dependent plasticity after the first years (https://solportal.ibe-unesco.org/articles/the-plastic-brain/). One of the ways to analyze experience-dependent plasticity is through the study of whether intervention or training can produce changes in brain functioning and structure. Numerous neuroimaging studies have reported alterations in functional connectivity or activation, structural changes, or other parameters of neuroplasticity as a result of cognitive or motor interventions beyond the age of 3 (see [8] for a review of those studies in primary school children and adolescents). In addition to neuroplastic changes, these interventions were associated with corresponding cognitive and behavioral changes such as increased attention (e.g., [9]), working memory (e.g., [10]), music (e.g., [11]), math (e.g., [12]) and reading performance (e.g., [13]). All of these studies associated practice in some cognitive skills by repetitive trials on tasks similar to those used in cognitive psychology laboratories or schools (these were the interventions or training) to neuroplastic changes beyond 3 years of age.

Altogether, convincing evidence for experience-dependent and experience-expectant plastic changes after the early years shows that the brain is modifiable throughout the school-age years. In terms of experience-dependent plasticity, this suggests that education–experiences in school– might have a main role in helping to shape the human brain during the childhood and adolescent years.

## Evidence of plasticity beyond the early years: old age

But does neuroplasticity extend even beyond childhood and adolescence? Intuitively, we know that most people can learn new things, regardless of their age; for example, you can teach your grandmother to use an iPhone or learn to play canasta at age 80. So it would make sense if there were evidence of brain changes in older adults, and there is.

However, plasticity for some functions, such as the motor function, seems to be lower in elderly people as product of expectant-dependent plasticity (see [14] for a review). For example, in a study[15] conducted in Spain and in the US, plasticity in 36 adults ranging from 19 to 81 years old was evaluated with transcranial magnetic stimulation (TMS). TMS is considered a noninvasive way to introduce plastic changes[[1]]: when TMS is applied repeatedly, neural connections strength decreases and motor function becomes blocked. So, for example, if you receive repeated TMS in the motor area associated with finger movement, you will not move your finger for a while, as a product of plasticity. That was exactly what was measured in the mentioned study, across ages, and results showed that older adults were less affected by the blocking. Those results suggest that motor cortical plasticity, as induced by repeated TMS, progressively declines across the human lifespan.

However, in motor function as well as in other domains, such as cognition there is evidence of similar degrees of change in the brain in elderly and younger people following intervention, i.e, experience-dependent plasticity (see [16] for a review). For example, in a study[17] conducted in the US, with adults ages 60 to 79 years, researchers measured the impact of aerobic exercise on brain structure. Fifty-five adults were divided into two groups, one receiving aerobic exercise lessons and the other stretching lessons, for 6 months. Brain structure was measured before and after those activities with MRI, and compared between the two groups. Results showed that aerobic exercise was associated with brain changes (i.e., the sparing of brain tissue) in aging humans. This finding illustrates that neuroplasticity is observed in elderly people, too, in association with a specific type of education (in this case, aerobic gym classes). This suggests that education can affect the human brain, in terms of plasticity, across the lifespan.

Of course, plasticity varies not only with educational experiences but also with the timing of exposition to those experiences, genes, and multiple interactions among those factors[18, 19]. These complex interactions are what make individual humans different from one another. Within those differences, research evidence lets us affirm that there are experience-expectant and experience-dependent neuroplasticity beyond age 3, and, indeed, across the lifespan.

## Conclusion

Overall, we are still far from having a full scientific picture of plasticity and development, but we do know that there is experience-dependent and experience-expectant neuroplasticity beyond the early years, even into old age. Plasticity might not be infinite[20], but there is evidence of significant plasticity across the lifespan.

What is the importance of this for educators and educational policymakers? The point is to know that, biologically, it never seems to be too late to learn something or to be taught something. The early years are very important, but subsequent years are important, too. There is room for learning, even in elderly people. The biological bases for brain change are present, with varying levels, across development, from infancy to old age.

[[1]] During an TMS session, an electromagnetic coil is placed against your scalp near your forehead. The electromagnet painlessly delivers a magnetic pulse that stimulates nerve cells in a specific region of your brain. TMS can also be applied repeatedly, and in that case it is called rTMS (repetitive transcranial stimulation). rTMS can induce changes in neuronal excitability that persist beyond the time of stimulation. rTMS at a low frequency (about 1 Hz) induces a decrease of cortical excitability, while higher frequency rTMS, (usually between 5 and 20 Hz), increases cortical excitability.

## References

1 Berens, A. E., Jensen, S. K. G. & Nelson, C. A. Biological embedding of childhood adversity: from physiological mechanisms to clinical implications. *BMC Med.* **15**, 1–12 (2017).

2 Nelson III, C. A. & Gabard-Durnam L. J. Early Adversity and Critical Periods: Neurodevelopmental Consequences of Violating the Expectable Environment. *Trends Neurosci.* **43**, 133-143 (2020).

3 Giedd, J. N. et al. Brain development during childhood and adolescence: a longitudinal MRI study. *Nat. Neurosci.* **2**, 861-863 (1999).

4 Mills, K. L. et al. Structural brain development between childhood and adulthood: Convergence across four longitudinal samples. *NeuroImage* **141**, 273-281 (2016).

5 Hedman, A. M., van Haren, N. E. M., Schnack, H. G., Kahn, R. S. & Hulshoff Pol, H. E. Human brain changes across the life span: a review of 56 longitudinal magnetic resonance imaging studies. *Hum. Brain Mapp.* **33**, 1987-2002 (2012).

6 Dima, D. et al. Subcortical volumes across the lifespan: Data from 18,605 healthy individuals aged 3–90 years. *Hum. Brain Mapp.* **43**, 452-469 (2022).

7 Frangou, S. et al. Cortical thickness across the lifespan: Data from 17,075 healthy individuals aged 3–90 years. *Hum. Brain Mapp.* **43**, 431-451 (2022).

8 Weyandt, L. L. et al. Neuroplasticity in Children and Adolescents in Response to Treatment Intervention: A Systematic Review of the Literature. *Clin. Transl. Neurosci.* **4**, 21 (2020).

9 Abend, R. et al. Brain structure changes induced by attention bias modification training. *Biol. Psychol.* **146**, 107736 (2019).

10 Olesen, P. J., Westerberg, H. & Klingberg, T. Increased prefrontal and parietal activity after training of working memory. *Nat. Neurosci.* **7**, 75–79 (2004).

11 Hyde, K. L. et al. Musical Training Shapes Structural Brain Development. *J. Neurosci.* **29**, 3019-3025 (2009).

12 Jolles, D. et al. Plasticity of left perisylvian white-matter tracts is associated with individual differences in math learning. *Brain Struct. Funct.* **221**, 1337–1351 (2016).

13 Romeo, R. R. et al. Socioeconomic Status and Reading Disability: Neuroanatomy and Plasticity in Response to Intervention. *Cereb. Cortex.* **28**, 2297–2312 (2018).

14 Oberman, L. & Pascual-Leone, A. Changes in plasticity across the lifespan: cause of disease and target for intervention. *Prog. Brain Res.* **207**, 91–120 (2013).

15 Freitas, C. Changes in cortical plasticity across the lifespan. *Front Aging Neurosci.* **9**, 5 (2011).

16 Cespón, J., Miniussi, C. & Pellicciari, M. C. Interventional programmes to improve cognition during healthy and pathological ageing: cortical modulations and evidence for brain plasticity. *Ageing Res. Rev.* **43**, 81-98 (2018).

17 Colcombe, S. J. et al. Aerobic exercise training increases brain volume in aging humans. *J. Gerontol. A Biol. Sci. Med. Sci.* **61**, 1166-1170 (2006).

18 Fandakova, Y. & Hartley, C. A. Mechanisms of learning and plasticity in childhood and adolescence. *Dev. Cogn. Neurosci.* **42** (2020).

19 Clayton, D. F. The role of the genome in experience-dependent plasticity: Extending the analogy of the genomic action potential. *Proc. Natl. Acad. Sci. U. S. A.* **117**, 23252-23260 (2020).

20 Thomas, M. S. C. Essay Review: Limits on plasticity. *J. Cogn. Dev.* **4**, 99-125 (2003).