Physical exercise practice and its implications for learning and memory

The benefits of physical exercise for health are well known. A lot of evidence support the effects of exercise on cardiovascular, endocrine, respiratory and other body systems' functions.

Series:
IBRO/IBE-UNESCO Science of Learning Briefings

Author/s:

Pâmela Billig Mello-Carpes
Professor, Federal University of Pampa (Unipampa), Brazil

Theme/s:

Physical exercise 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

- Physical exercise has beneficial effects on brain health.
- Neuroplasticity is the basis of learning and memory, and physical exercise influences the neuroplasticity.
- Physical exercise positively modulates attention, anxiety, mood, emotions, and other variables that are known to influence cognition and learning.
- Acute physical exercise has different effects compared chronic physical exercise, and it can be an effective strategy to improve learning if it is properly implemented.
- The adoption of long-life regular physical exercise practice should be stimulated in school.

Introduction

The benefits of physical exercise for health are well known. A lot of evidence support the effects of exercise on cardiovascular, endocrine, respiratory and other body systems' functions. In the last years, the effects of regular physical exercise on the brain has been widely studied, and the positive effects of exercise on brain function have been well- established[1,2].

Regular physical exercise requires the regular exercise practice. Besides the frequency of practice, the type, intensity and duration of exercise have differential effects on brain function[3]. Prioritizing regular physical exercise can be challenging, but it should be seen as an important goal and should be stimulated from early in life and included in educational contexts.

The neurobiological basis of learning and memory

Facilitation of learning is often considered the main objective of teachers. In view of this, it is important that they know the neurobiological basis of learning and memory. This knowledge can empower teachers to adopt a more evidence-informed practice[4].

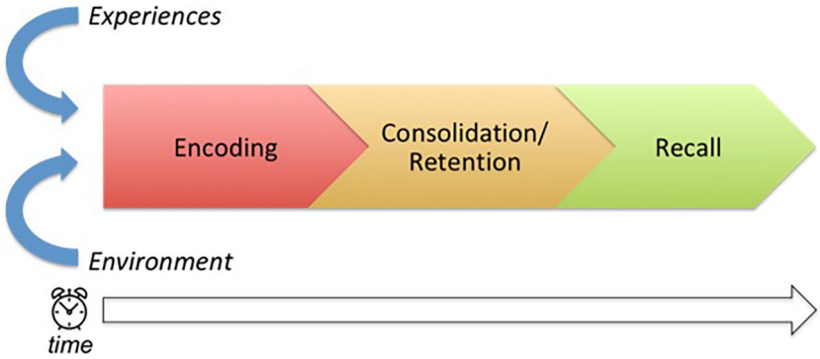

Fig 1. Memory corresponds to the encoding, consolidation and recall of information.

Learning involves the encoding stage of memory (figure 1). We can define learning as the acquisition of information from the experiences and environment. This information can be maintained for some time, and maybe be recalled latter, so, it requires the storage of information in the brain (consolidation of memory); in other words, learning can be consider as an initial phase necessary to memory formation[5].

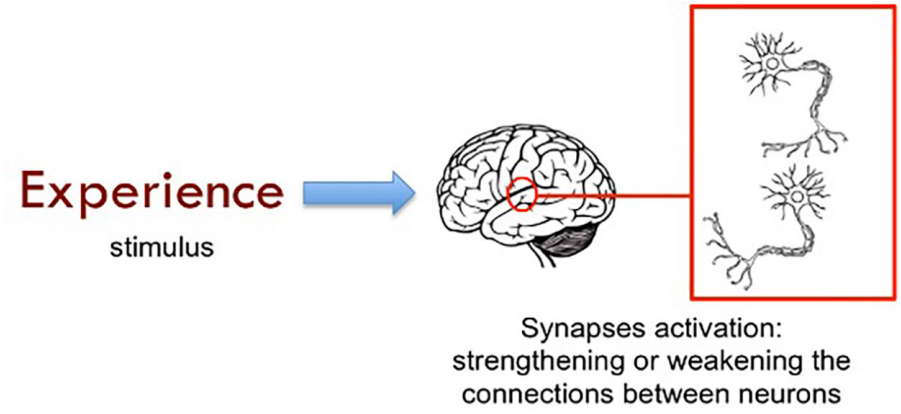

Fig 2. Learning corresponds to the activation of synapses by one stimulus from the environment/experience, changing the connections between neurons.

Neurons and glial cells compose our brain. The neurons are the most studied brain cell, clearly involved in the learning and memory processes. The neurons communicated to each other by synapses. In neurobiological terms, we could say that learning corresponds to the activation of synapses by one stimulus from the environment/experience, strengthening or weakening the connections between neurons (figure 2). According the stimulus, it can lead to permanent changes in the activated synapses, promoting modifications and synapses stabilization (so, the information is stored in these synapses). Later, if an related stimulus is received, this synapse can be activated to memory recall. The brain and neurons ability to change (temporary or permanently) from stimulation is called neuroplasticity, and can occur in different levels, from neuronal molecules to whole brain[5].

Physical exercise, neuroplasticity and brain health

Basic and applied neuroscience research conducted both through the use of animal models as well as with human participants has revealed that physical exercise has positive effects on learning, memory and on brain health in general, improving brain blood supply, synaptic transmission, neurotrophic factors, and others[1,2,6-8].

There are different mechanisms by which physical exercise influences the brain health (figure 3):

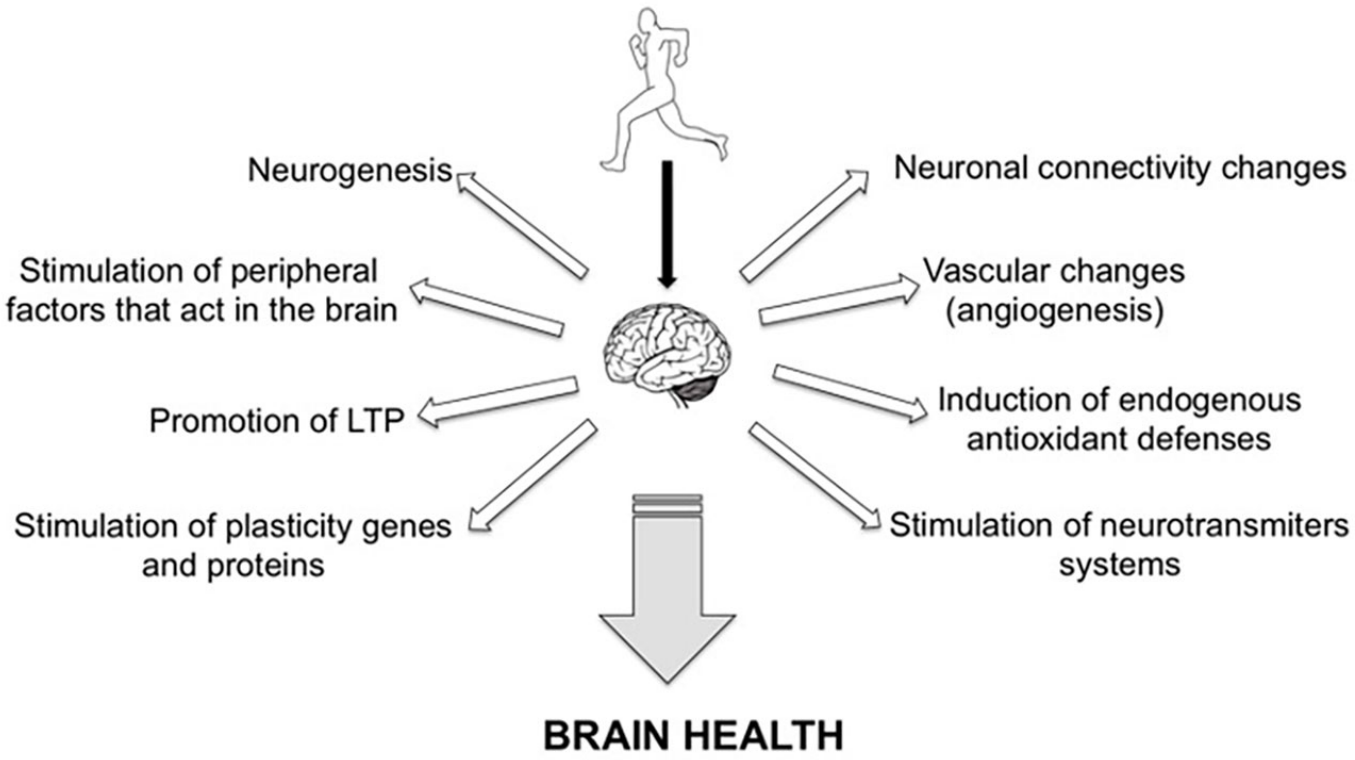

Fig 3. Regular physical exercise influences the brain health by multiple ways.

- Promotion of neurogenesis, which means the production of new neuronal cells, mainly in hippocampus[i][1];
- Stimulation of peripheral factors that cross the blood-brain barrier and act in the brain, as glucocorticoids, estrogen, endorphins and growing factors[1] – these substances influence brain neuroplasticity[9-10];
- Promotion of Long-Term Potentiation (LTP), a lasting improvement in synaptic transmission that is considered the basis of memory consolidation and is highly related to neuroplasticity[11,12];
- Stimulation of plasticity-related genes and proteins, as the Brain-Derived Neurotropic Factor, a member of the neurotrophin family of growth factors, related to neuronal survival, neuroplasticity and neurogenesis[1];
- Promotion of neuronal connectivity (synaptic) changes[1];
- Promotion of angiogenesis, it is, production of new blood vessels, which guarantee blood flux and energy substrate to brain cells[13];
- Induction of endogenous antioxidant defences, which protects the brain and reduces the risk of diseases in general[14];
- Stimulation of neurotransmitters systems, which can results in a more efficient synaptic transmission[1,15].

Considering these different mechanisms by which physical exercise can promote learning and memory improvements. But which form of exercise has shown to have the largest benefits when it comes to improving memory functions? Is it Aerobic (running, swimming) or anaerobic (force, coordination, balance) exercise? Currently, it is hard to provide a clear answer to this question as most of the research on the effects of exercise on cognition and the brain has focussed on the effects of aerobic physical exercise and less is known about the effects of anaerobic exercise. So, what is possible affirm is that aerobic regular physical exercise can promote brain health and learning benefits[1,2,6,8,11,15]. It is important remember, however, that, besides the type of exercise, the frequency of practice, the intensity and the duration influence its effects on brain[3]. To have positive learning modulation the exercise practice should be regular (at least 2-3 times per week) and with moderate to high intensity[3]. Furthermore, aerobic physical exercise has been investigated as a neuroprotective strategy in models of aging and neurodegenerative disease; the evidences suggest that it can protect the brain, decreasing the velocity of neuron loss and memory decline related to aging and neurodegenerative diseases[3,7]. In fact, research suggest that physical exercise should be practiced across the lifespan since this will contribute to better brain health and function and could protect against/lessen the probability of the onset of neurodegenerative diseases.

Other benefit of physical exercise to the brain

Beyond the effects of physical exercise on neuroplasticity that are directly related to learning and memory improvements, it is important consider that exercise can modulate other cognitive functions that are important to memory processes success, as attention, anxiety, mood, emotions, and others.

Educational spaces, like schools, should be environments that promote positive emotions and mental states, in such a away that they contribute to leaning and memory formation[16,17]. However, frequently students present with stress, anxiety, attention deficits, poor sleep quality or lack of sleep, which could be related to exams and tests, uncertainties about the future, bullying, and others[18-20].

Physical exercise may help with such difficulties, since it is well known to be associated with decreases in anxiety and stress[20]; physical exercise has also been shown to promote positive mood and well being, arguably because exercise is known to induce the release of endorphin and serotonin[ii][21]; has a positive effect on attention states[iii] and executive functions[iv][22]; improves the sleep quality[23]; and others. Additionally, research has shown that chronic physical activity programs are associated with positive effects on preadolescent children academic performance[22,24]. Furthermore, brief periods of physical exercise periods are associated with positive changes in the attention of students[24]. So, these are additional benefits of exercise to brain function that can potentiate the learning processes.

Acute physical exercise and possible effects on learning

Although the effects of regular (chronic) aerobic physical exercise on learning and memory has been the focus of research in this area, recently some researchers have begun to investigate the effects of acute exercise (just one physical exercise session, for example) on cognitive functions. These researchers generally use a one physical exercise session in a learning context, before or after a learning session, with the intention to improve learning quality and memory consolidation.

Studies using animal models to study the effects of exercise as well as research with human adults and the ageing population have revealed that a single physical exercise session can improve the learning, promoting a better memory, that persists for a longer time[15,25-26]; in general, most of these studies promote an exercise session immediately after a learning session. The effects of this type of strategy involves the modulation of learning quality; with a better learning we can promote a better memory consolidation, so, the studies investigating the effects of this type of intervention have seen persistent effects on learning and memory[15,25-26]. For example, a weak memory, that normally persist for 24h on rodents, persists for al least 21 days if an physical exercise session was performed after the task learning session[15].

The neural mechanisms underline the effects of acute exercise are still being investigated, but some evidence suggest that they involve the induction or increase of some neurotransmitter[v] release (peripheral and on brain), as norepinephrine and dopamine (these neurotransmitters are also related to memory persistence, i.e., when they are release by neural pathways they help to promote better memory consolidation)[15,26], as all as changes in growth factors[vi], and neuromodulators[vii][25]. All these changes help to improve the brain activation, the neurons communication and the neuroplasticity, so, influence the learning and memory, qualifying these processes. Additionally, these changes can modulate cognitive processes, as attention[25], what can explain the acute physical exercise effects on learning improvement.

Considering this set of findings, it is interesting to consider acute physical exercise as a strategy for improving learning when it is properly implemented nearly to a learning experience. In educational contexts, it was previously demonstrated that short aerobic exercise breaks developed along the class time boost the attention of students[24].

Practical educational implications

Seeing that is well established that physical exercise is associated with learning improvement, it could be considered in the educational contexts. In these sense, some suggestions are made:

- Policy makers and governments: Policies to promote physical exercise in schools are critical, and they could start by ensuring that education professionals are aware of the effects of regular physical exercise practice on learning and memory. It is well known the effects of exercise to others health aspects, even for mental health in general, but not all people involved in education know the specific effects of physical exercise to learning. Investments in adequate spaces to a safe practice of exercise is important too, as well as the hiring of trained professionals to prescribe and monitor the practice of physical activities, since the frequency, duration, type and intensity of exercise are crucial factors to guarantee the desired effects. Beyond this, policy makers need to fund playgrounds, curricula that have regular recess, more physical education teachers, better programs for physical education which are evidence informed.

- Schools managers and scholars environments: Schools should stimulate physical activity practice. If in some countries it is normal that children are provided with spaces within which to be physically active, in others this is not necessarily the case. The ideal would be that all schools have spaces within which students can engage in physical exercise, with trained professionals to instruct the students. The time for physical exercise practice should be consider as a curricular time, and all the people involved (teachers, students, parents, and all scholar community) should be know the relationship between physical exercise and learning. School also could promote campaigns to stimulate the students to have a more physical activity life, in school and out of it, since nowadays most of them spent a lot of time with sedentary activities, as electronic games and Internet.

- Teachers: Although talk about the benefices of physical exercise to general health is generally included in some classes in worldwide schools, talk about its benefices to brain and learning improvement is not only important, but also a tool that the students can use to improve her/his school performance. It is usually commenting with students about the benefits of exercise for the heart, prevention of diseases such as diabetes, etc. Why not comment on the benefits of exercise for the brain for learning and preventing neurodegenerative diseases such as Alzheimer's? Teachers also should valorise the physical exercise practice on educational context, and could include in their classes some breaks to physical activity

practice, if possible, immediately after a new content learning – there are evidences that this practice improve students' learning.

[i] The hippocampus is a structure of temporal brain lobes that is intrinsically related to memory acquisition and consolidation.
[ii] Endorphin and serotonin are chemical substances classically involved in well-been states. Different stimulus can promote their release, including the physical exercise practice.
[iii] Atentional states refer to the attentional level and the ability to focus on certain specific stimuli, directing sensory and/or cognitive resources to perform a given task, and is fundamental to learning. For more specific information please see the brief about attention[27].
[iv] Executive functions correspond to a set of basic cognitive processes that include attention control, working memory, cognitive flexibility, inhibitory control and cognitive inhibition. They develop throughout life and are important to we can resist to act impulsively, select our attentional focus, think creatively, and adapt to changes situations.
[v] Neurotransmitters are chemical molecules produced by neurons and used to synaptic communication.
[vi] Neuronal growth factors are small proteins, important for the growth, maintenance and survival of certain neurons.
[vii] Neuromodulators are substances released in the synapses that act modulating the communication between neurons. They produce slower and more discrete effects than those generated by neurotransmitters.

References

1. Cotman, C.W. & Berchtold N.C. Exercise: a Behavioral Intervention to Enhance Brain Health and Plasticity. Trends in Neuroscience doi: 10.1016/S0166-2236(02)02143-4 (2002).

2. Vivar, C. &van Praag, H. Running Changes the Brain: the Long and the Short of It. Physiology doi: 10.1152/physiol.00017 (2017).

3. Schimidt, H., Mello-Carpes, P.B. & Carpes F.P. The role of regular physical exercise for enhancement of long-term memory: a review of recent evidences. Pan American Journal of Aging research doi: 10.15448/2357-9641.2015.2.21786 (2016).

4. Marope, P.T.M. Brain Science, Education, and Learning: Making Connections. Prospects doi: 10.1007//s11125-017-9400-2 (2016).

5. Tovar-Moll, F. & Lent, R. The Various Forms of Neuroplasticity: Biological Bases of Learning and Teaching. Prospects doi: 10.1007//s11125-017-9400-2 (2016).

6. Mello, P.B., Benetti, F., Cammarota, M., Izquierdo, I. Effects of acute and chronic exercise and stress on different types of memory in rats. Anais da Academia Brasileira de Ciências doi: 10.1590/S0001-37652008000200008 (2008).

7. Prado Lima, M.G. et al. Enviormental enrichment and exercise are better than social enrichment to reduce memory deficts in amyloid beta neurotoxicity. PNAS doi: 10.1073/pnas.1718435115 (2018).

8. Rasberry, C. N. et al. The association between school-based physical activity, including physical education, and academic performance: A systematic review of the literature. Prev. Med. doi:10.1016/j.ypmed.2011.01.027 (2011).

9. McGaugh, J.L. &Roozendaal, B., Role of adrenal stress hormones in forming lasting memories in the brain. Current Opinion on Neurobiology doi: 10.1016/S0959-4388(02)00306-9 (2002).

10. Paletta, P., Sheppard P.A.S., Matta, R., Ervin, K.S.J. & Choleris, E. Rapid effects of estrogens on short-term memory: Possible mechanisms. Hormones & Behavior doi: 10.1016/j.yhbeh.2018.05.019 (2018).

11. D'Arcangelo G., Triossi, T., Buglione, A., Melchiorri, G. & Tancredi, V. Modulation of Synaptic Plasticity by short-term aerobic exercise in adult mice. Behavioral Brain Research doi: 10.1016/j.bbr.2017.05.058 (2017).

12. Izquierdo, I., et al. The evidence for hippocampal long-term potentiation as a basis of memory simple tasks. Anais da Academia Brasileira de Ciências doi: 10.1590/S0001-37652008000100007 (2008).

13. Kerr, A.L., Steuer, E.L., Pochtarev, V. & Swain, R.A. Angiogenesis but not neurogenesis is critical for normal learning and memory acquisition. Neuroscience doi: 10.1016/j.neuroscience (2010).

14. Powers, S.K., Jackson, M.J. Exercise-induced oxidative stress: cellular mechanisms and impact on muscle force production. Physiological Reviews doi: 10.1152/physrev.00031.2007 (2008).

15. da Silva de Vargas, L., Neves, B.S.D., Roehrs, R., Izquierdo, I. & Mello-Carpes, P. One-single physical exercise session after object recognition learning promotes memory persistence through hippocampal noradrenergic mechanisms. Behavioral Brain Research doi: 10.1016/j.bbr.2017.04.050 (2017).

16. Izquierdo, I. Memória. 2nd edition. Porto Alegre: Artmed (2011).

17. Pekrun, R. Emotions and Learning. Educational Practices Series 24. International Bureau of Education – UNESCO (2014).

18. Ostberg, V., Laftman, S.B., Modin, B. & Lindfors, P. Bullying as a Stressor in Mid-Adolescent Girls and Boys – Associations with Perceived Stress, Recurrent Pain, and Salivary Cortisol. International Journal of Environmental Research and Public Health doi: 10.3390/ijerph15020364 (2018).

19. UNESCO. School Violence and Bullying: Global Status Report. Available on: http://unesdoc.unesco.org/images/0024/002469/246970e.pdf (2017).

20. Machado, R.S., Mello-Carpes, P.B. O Tai Chi Chuan reduz o estresse e a ansiedade na escola? Revista Ciência em Extensão. Available on: http://ojs.unesp.br/index.php/revista_proex/article/view/1897 (2018).

21. Yan, Z., Okutsu, M., Aktar, Y.N., Lira, V.A. Regulation of exercise-induced fiber type transformation, mitochondrial biogenesis, and angiogenesis in skeletal muscle. Journal of Applied Physiology doi: 10.1152/japplphysiol.00993.2010 (2011).

22. de Greeff, J.W., Bosker, R.J, Oosterlaan, J., Visscher, C. & Hartman, E. Effects of physical activity on execute functions, attention and academic performance in preadolescent children: a meta-analysis. Journal of Science and Medicine in Sport doi: 10.1016/j.jsams.2017.09.595 (2018).

23. Mendelson, M., et al. Sleep quality, sleep duration and physical activity in obese adolescentes: effects of exercise training. Pediatric obesity doi: 10.1111/ijpo.12015. (2016).

24. Kubesch, S., et al. A 30-Minute Physical Education Program Improves Students' Executive Attention. Mind, Brain, and Education doi:10.1111/j.1751-228X.2009.01076.x (2009).

25. Basso, J.C. & Suzuki, W.A. The Effects of Acute Exercise on Mood, Cognition, Neurophysiology, and Neurochemical Pathways: A Review. Brain Plasticity. doi:10.3233/BPL-160040 (2017).

26. Segal, S.K., Cotman, C.W. & Cahill, L.F. Exercise-Induced Noradrenergic Activation Enhances Memory Consolidation in Both Normal Aging and Patients with Amnestic Mild Cognitive Impairment. Journal of Alzheimers Disease doi:10.3233/JAD-2012-121078 (2012).

27. Mello-Carpes, P.B. Attention and its importance to learning. IBRO/IBE-UNESCO Science of Learning Briefings (2018).