Physiological aspects that impact education[1]

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According to the UNICEF Innocenti Report card 18, more than 69 million children live in poverty (UNICEF Innocenti, 2023) in countries from OCDE and the European Union. Poverty can be measured as monetary deprivation, as well as non-monetary deprivation. Non-monetary poverty represents basic things that children are deprived of, such as nutrition, water, sanitation, clothing, housing, education, health, information and play. Consequently, children living in poverty are subjected to a multitude of disruptive factors that undermine their education, with substantial negative outcomes for adulthood (HARMS; GARRET-RUFFIN, 2023). This multitude of disruptive factors are directly associated with the children's physiology and well-being. Here we will discuss how physiological factors coexist with psychological factors in cognition and school learning, with special emphasis on nutrition, physical activity and sleep.

Nutrition

Full cognitive development depends, in part, on the maturation of the nervous system. It benefits from several factors, including diet, physical activity, and sleep (SIGMAN et al., 2014). The mechanisms by which those factors are associated with health, and particularly learning and cognition, have been detailed in the past decades. Devastating impacts on the development of the nervous system as a consequence of nutritional deficits have been reported, mainly due to insufficient or inappropriate maternal nutrition (ANJOS, et al 2013). Nutritional deficiencies can also impair academic performance throughout childhood to adolescence. Furthermore, it is not just the quantity of food eaten in the first years of life, but also its quality that affects cognitive performance during school life (ABOUD; YOUSAFZAY, 2015). Nutritional aspects also influence brain development, in spite of the genetic program and other environmental factors related to the brain development. Maturation of the brain follows a temporal sequence with gradual changes in the neural circuits beginning with the sensory systems, followed by the motor system and finally the cognitive and emotional systems (HENSCH, 2005). Hence, brain plasticity promotes brain development, and the first years of life (up to 5-7 years) is the critical period for sensory systems development (TAU; PETERSON, 2010), whereas motor and cognitive circuitry extend until the end of adolescence (HENSCH, 2005).

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The neural circuitries developed during this period of life will provide the basic substrate for the learning processes. Importantly, the brain is particularly sensitive to environmental stimulation and vulnerable to adverse conditions such as dietary deficiencies and, not less important, early life stress (LUPIEN et al 2009, INNIS, 2011, NYARADi et al 2013).

Under this framework, nutritional restriction of essential amino acids - those that can only be acquired through food, such as tryptophan - impairs the development and plasticity of visual system circuitry in animal models (PENEDO et al 2009). Similarly, nutritional restriction of omega-3 fatty acids, in particular docosahexaenoic acid (DHA), substantially alters the parameters of circuits development and the temporal course of critical periods of plasticity (de VELASCO et al., 2012; 2015). Children with delay in the development of visual acuity and learning deficits have been reported as presenting significant alterations in DHA bioavailability (INNIS, 2008; 2011). Furthermore, high-fat diets may hinder learning, according to evidence from animal studies (BEILHARZ et al., 2014).

These studies highlight the importance of nutrition during early childhood, meaning that malnutrition is one significant aspect that can alter the time course and connectivity of the developing brain, with impact on learning ability during school period. Nonetheless, adequate nutrition is important for learning and education throughout life, since numerous learning related processes depend on it, such as DNA synthesis, cell proliferation, and neurotransmitter metabolism (ANJOS et al., 2013). As an example, the nervous system grey matter, formed by neuronal and glial cells, reaches its maximum development between 7 and 11 years of age. Meanwhile, the white matter, composed mainly of axonal fibers, continues its maturation and development until early adulthood (NYARADI, et al., 2013). To overcome nutritional deficiencies, studies have shown positive effects of interventions with dietary micronutrient changes on short-term memory (KHOR; MISRA., 2012). Besides the evidence from interventional studies, children living in food insecure conditions are twice as likely to have hyperactivity and attention problems when compared to those living in an environment with food security. Childhood hunger is a strong predictor of mental health. Children from household food insecurity settings present 27.9% higher rates for depressive symptoms in comparison to children from not food insecure households (THOMAS; MILLER & MORRISSEY, 2019). Furthermore, hunger has been associated as a predictor of depression and suicidal ideation in adolescents and early adulthood (McINTYRE et al., 2013). Besides, these children perform worse in language comprehension tests with considerable delays in emotional, motor, and cognitive development (see references in KE; FORD-JONES., 2015).

Development of healthier eating habits must be part of school activities. Good examples are the gardening activities and their positive effects on preference and consumption of vegetables by elementary school children (DUDLEY et al., 2015). It is remarkable that increasing the access to vegetables also reduces the reluctance to experiment with new types of food. Children and adolescents present a higher rate of glucose usage in comparison to adults, as well as higher cerebral blood flow and oxygen usage by the brain. Also, children and adolescents spend longer times sleeping during the night in comparison to adults, making them susceptible to longer periods of fasting. Consequently, they are particularly affected by the positive effects of eating breakfast. In recent decades, several studies have evaluated the effect of breakfast intake on the cognitive performance of children and adolescents (WILLIAMS, 2014). In most of them, beneficial effects are reported (ANZMAN-FRASCA et al., 2015). However, due to the heterogeneity of the studies – related to factors such as the composition of the meal, the type of tasks evaluated, and the time between eating breakfast and performing them – it is not possible to establish a relationship between the amount of energy ingested, the composition of breakfast, and academic performance. For this reason, the widespread idea that breakfast should provide at least 20% of the daily energy needed to benefit cognitive performance still needs to be confirmed by more controlled studies (EDEFONTI et al., 2014).

School feeding programs are essential for educational progress. These programs have multiple positive effects, from reducing absenteeism to significantly improving cognition and academic performance, especially when associated to micronutrient supplementation and deworming strategies (BUNDY et al., 2012). Besides, research in the school environment testing the immediate effects of nutrition on academic performance is still incipient. There is a need for quantitative evaluation of the impact of caloric intake, meal composition, micronutrients, hydration, portion size, food frequency, feeding window and the rewarding values of food on academic performance. Furthermore, the complex interaction between nutrition, sleep and exercise should be carefully considered.

Physical Activity

The brain benefits from physical activity. Animal research indicates that physical activity in early life improves functioning of neural networks involved in memory and creates a reserve of precursor cells that influences learning abilities (FABEL et al., 2009). Furthermore, physical exercise during pregnancy increases the number of cells in the hippocampus of rats whose mothers undertook physical exercise (GOMES DA SILVA., 2015).

In humans, evidence indicates that physical activity in childhood and adolescence may be beneficial for cognitive performance and learning. In fact, a positive correlation between physical activity and learning levels and intelligence has been observed in school-age children (SIBLEY and ETNIER, 2003). For example, a single bout of moderate exercise in 9- and 10-year-old children can alter electroencephalographic (EEG) activity and improve reasoning on tests of academic achievement (HILLMAN et al., 2009). In addition, aerobic exercise can increase the state of attention in assessments, with better results in tasks and clearer reading comprehension (HILLMAN et al., 2009). Importantly, acute exercise may also be beneficial for children with Attention-Deficit/Hyperactivity Disorders (ADHD) in normalizing arousal and alertness as measured by EEG (HUANG, et al., 2018). Children and adolescents who engage in regular physical activity also have faster cognitive processing (BUCK et al., 2008). Based on these results, Aberg et al. (2009) investigated the relationship between physical fitness (cardiovascular) and cognitive performance during adolescence. The study followed 1,200,000 adolescents aged 18 years and older who were enlisted in the military forces in Sweden. Adolescents who showed cardiovascular improvement between the ages of 15 and 18 performed better on intelligence tests than those with lower physical condition in the same period. To test if the results could reflect a genetic or familial influence, the researchers analyzed 3,147 pairs of twins, of which 1,432 were identical. It was observed that environmental factors, and not genetic ones, exerted an influence on this relationship (ABERG et al., 2009).

Better physical fitness is associated with greater volume of brain structures in areas related to learning and memory, as well as with brain plasticity, which would result in better academic performance (CHADDOCK-HEYMAN et al., 2015). Furthermore, physical exercises require the engagement of attention and other executive functions, motor coordination, cognitive challenge and social interaction. As discussed above, adolescence is an important stage for brain maturation. Results presented in a systematic review indicated significant changes in brain structure or function after a physical intervention, such as white matter integrity and activation of regions associated with cognition (VALKENBORGHS et al., 2019). Despite these promising results, further studies on the subject are still needed to investigate what type, frequency, and duration of activities are most appropriate for each age group to obtain the best possible effect on cognition and academic performance (DONNELLY et al., 2016). In any case, public and school policies should prioritize systematization of programs to encourage the practice of exercise and physical activity throughout basic education.

In this sense, physical activity can be understood as any body movement produced by skeletal muscle contraction that increases energy expenditure, which includes everything from a structured training program to freer activity such as playing, running, jumping, spinning. Consequently, the options for physical activity in the school environment are very varied, such as: dancing, playing ball, jumping rope, or playing tag and much more.

The recommendation of the World Health Organization (WHO) is that children and adolescents have at least 60 minutes of physical activity per day (or 2 sessions of 30 min/day), if there is no medical indication to the contrary. This recommendation applies to youth ages 5 to 17 of all races, genders, socioeconomic conditions, and regions. However, the type and intensity of physical activities vary among individuals. Aerobic activities with moderate and vigorous intensities are the most recommended on a daily basis. Even so, strength activities, such as high and long jumps and javelin and discus throws, can be incorporated into students' physical training at least 3 times a week. For inactive young people, a progressive increase in the practice of physical activity is recommended so that, finally, they reach the established goal of 60 minutes per day. It is advisable to start with little activity and gradually increase the duration, frequency, and intensity over time. Episodes of physical activity greater than 60 min/day may provide additional health benefits, even though sedentary children would definitely benefit even from physical activity below recommended levels (WHO, 2011). Raising students' awareness of the importance of regular physical activity has become widely needed, and can occur through physical education classes, or through transdisciplinary projects. Thus, systematic daily activities can be stimulated in the form of games, sports, scavenger hunts and the like, according to the interest and development of students in their different age groups. To this end, all members of the school community should encourage students to engage in physical activity for at least 60 minutes a day, seven days a week. In order to implement quality physical education programs, several barriers need to be overcome, including: lack of facilities and time, dense curricula, insufficient infrastructure, shortage of physical education teachers, and low level of professional development. Curricular classroom lessons should be designed to integrate physical activity with other disciplines in order to facilitate learning and improve school performance.

Sleep

A large part of the adult population suffers from insufficient sleep (FORD et al., 2015). Sleep problems are associated with obesity and increased cardiovascular risk (COVASSIN; SINGH, 2016). Negative health impacts due to socioeconomic disadvantages can be mediated by decreased sleep duration and quality.

Low maternal education, overcrowded household environments, and poverty are associated with worse sleep routines (GRANDNER et al., 2015). The invention and spread of electric light and numerous electronic devices have led to a substantial decrease in sleep time worldwide (MORENO et al., 2015). It is estimated that the average daily sleep duration in adult individuals has dropped from 9 hours in 1910 to about 7.5 hours today (FORD et al., 2015). Artificial light has effects that overlap with those produced by the natural light-dark cycle, possibly causing a misalignment of circadian rhythms. Sleep reduction is more pronounced in individuals of low socioeconomic status, reaching a reduction of 3.8 hours in some occupations. Adverse conditions that lead to sleep problems include unsafe environment, overcrowded sleeping quarters, uncomfortable housing conditions (temperature, sound, etc.), as well as stress and anxiety (GRANDNER et al., 2015). Sharing a bed with other individuals can expose children to sleep disturbances and anxiety due to noise, movement, dirt, and other factors that together have a negative impact on cognition. Many studies show that these conditions increase the number of nocturnal awakenings, reduce total sleep time, and produce chronic sleep deficit (MILEVA-SEITZ et al., 2015). Sleep problems during adolescence are deleterious to emotional balance and self-regulation, increasing the chance of risky behaviors (THOMAS et al., 2014). Socioeconomic status can have a direct impact on sleep deficit because children of low socioeconomic status often need to work to supplement the family income. Sleep deficit is one of the main physiological bottlenecks for learning. Multiple lines of evidence indicate that sleep plays a crucial role in metabolic detoxification, neurotransmitter replenishment, and activation of molecular cascades involved in synaptic remodeling (RIBEIRO, 2012). Sleep favors learning both before and after the acquisition of new memories (RASCH & BORN, 2013). In laboratory experiments, it has been well demonstrated that a person who has not slept well at night will be poorly able to learn unless he or she can sleep before training (MCCOY; STRECKER, 2011). On the other hand, a person who has just learned new things usually benefits from a post-class nap, capable of promoting the selection, consolidation and restructuring of memories, as well as their integration with pre-existing memories (LEMOS et al., 2014). Sleep acts, therefore, in the preparation, consolidation, and transformation of memories.

Current knowledge already provides us with subsidies for proposing changes in the school organization in order to meet the sleep needs of students (REDEKER, 2016). The opportunity for a siesta, the nap after lunch, should be offered throughout early childhood education. In addition, there is a clear inadequacy in the start time of classes. The time of seven o'clock in the morning, which is quite widespread in our country, is inadequate, especially for adolescents, who have greater difficulty in anticipating the beginning of the night's sleep.

When subjected to a later school start time (from 7:30 to 8:30) adolescents presented multiple positive outcomes, from increased sleep duration, to better mood profiles (ARAUJO et al., 2022). For all these reasons, the investigation of sleep as a cognitive tool in school learning is of great interest. Future research should elucidate the best way to use this pedagogical resource, which is still almost unexplored. In particular, it is crucial to evaluate the cognitive effects related to sleep timing, duration, the composition of different physiological states, and interactions with physical exercise and nutrition.

What we still need to investigate (Research suggestions)

1. Quantify the cognitive impact of caloric intake, meal composition, micronutrients, hydration, as well as the effects of portion size, of the frequency of food and the reward value of the food.
2. Deepen knowledge about the type, frequency and duration, and timing of the most appropriate physical activities for each age group.
3. Determine the influence of different phases and types of sleep on people's memory, cognition and emotion.

What Needs to Be Done (Public Policy Suggestions)

1. Provide the school system with adequate conditions to offer meals with a composition consistent with scientific data, especially at breakfast.
2. Provide elementary schools with vegetable and gardening activities.
3. Provide schools with physical activity equipment, and equip them with bodies of teachers specialized in this area.
4. Include at least 60 minutes of daily physical activity in the schedule guided by physical education teachers.
5. Enable changes in the timetable that allow, on a time basis full-time, start morning activities at 8:30 a.m. in all grades, as well as how to provide conditions for a nap after lunch, for children in kindergarten and elementary school.

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