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EPIGENETICS GIVES NEW KNOWLEDGE ABOUT LEARNING – THE EXAMPLE PHYSICAL EDUCATION

Birgitta Mc Ewen
Department of Health, Karlstad University, Karlstad, Sweden

New knowledge in biology accumulates fast. This has great implications, for example, for our views of learning. Brain research, as well as research in the new field of epigenetics, have been very intense during the last few decades, and will doubtless influence our view of learning. It is important to follow the development in biology, derive advantages from new insights, and to consider changed practices at school. This paper is an example of how an increased amount of physical education in the school timetable could increase performance in theoretical school subjects. This relation is discussed in the light of the recently discovered epigenetic mechanisms. Studies have revealed epigenetic modifications in the brain cells during learning. Learning, combined with physical activity, has revealed increased epigenetic modifications. Thus, it has been speculated that epigenetic mechanisms might explain improved results in theoretical subjects due to physical activity. This ought to have implications for the school timetable, and lead to more physical education at school. It is discussed that one of the easiest ways to improve results in theoretical school subjects could be to increase the amount of physical education in the school timetable.

Keywords: Curriculum, Learning and Neuroscience, Nature of Science

INTRODUCTION

This paper has a theoretical approach, discussing how our understanding of prerequisites for learning has changed due to novel biological knowledge, and how this might have consequences in a school context. Noteworthy, knowledge about learning relies on what we know about biological processes in our bodies and particularly in our brains. During the last few decades, understandings about how the human brain works have accumulated quite rapidly (Huth et al., 2016; McNaughton et al., 2006). For example, it was long thought that the brain could not synthesize new neurons after childhood and adolescence. However, in 1998, Eriksson and colleagues (Eriksson et al., 1998) showed that new neurons are synthesized also in grown-ups. This was pioneering work, indicating that the human brain retains its ability to generate neurons throughout life, possibly leading to a changed view of learning.

Also included in this new biology knowledge is the concept of epigenetics, which is a molecular model explaining when genes are active or not. Thus, we now know more about the mechanisms for when different genes are “switched on” to be in an active state or when they are “turned down” to be passive or silent. This has a tremendous effect on the whole organism, and in practice decides its physiology. Learning is one of these processes where epigenetic mechanisms have been shown to operate. As we learn more about epigenetic processes, we also learn more about prerequisites for learning. Interestingly, it has been found
that the environment could influence gene expressions. Through different environmental stimuli, molecules in our bodies transport and mediate a response to the cell machinery, to impact if genes should be active or not. Owing to the immense consequences that the knowledge of epigenetic mechanisms will have, many biologists have predicted epigenetics to result in a paradigm shift within biology (Gilbert & Epel, 2009).

Due to these new data, our comprehension about prerequisites for learning has changed. The aim of this paper is to highlight the importance of new knowledge and how it could be translated into practice at school. The chosen example is the school subject physical education. It has been shown that an increased amount of physical education in the curriculum can improve results in theoretical school subjects (Chomitz et al., 2009; Fedewa & Ahn, 2013; Ericsson, 2012; Fritz, 2017; Käll et al., 2014; Raspberry et al., 2011; Spitzer & Hollmann, 2013; Van Dusen et al., 2011). In this paper, it is speculated that the correlation between improved school results and more physical education in the curriculum could be due to, at least partly, epigenetic mechanisms. This shows that we have to be acquainted with new biological knowledge and that this could change our view of prerequisites for learning.

EPIGENETICS – DEFINITIONS, MECHANISMS, AND THE CONNECTION BETWEEN GENES AND THE ENVIRONMENT

The word “epigenetics” was first coined by the development biologist Waddington in 1968 (see Van Speybroeck, 2002). The term described how an embryo develops, according to a well-defined pattern. A parallel origin came from Nanney (1958), who more specifically referred to it as the expression of genes. Since then, the term has been redefined. Gilbert and Epel (2009) defined it as “those genetic mechanisms that create phenotypic variation without altering the base-pair nucleotide sequence of the genes” (p. 12), and Riggs and Porter (1996) as: “the study of mitotically and/or meiotically heritable changes in gene function that cannot be explained by changes in DNA sequence” (see Allis et al., 2015, Chapter 1, p. 2).

“Epi” comes from the Greek word “over, above.” The word epigenetics aims at mechanisms acting “above” the sequence of base-pairs in the DNA. There are many types of epigenetic mechanisms (Kouzarides, 2007; Allis et al., 2015). The most studied are: DNA methylation, modification of histones, and epigenetic control made by small regulatory microRNAs (Semaan & Kauffman, 2013), see Figure 1. In principal, the different epigenetic mechanisms “open up” or “close” the genes. When they are “opened up,” they will be active, while silent when “closed down.” Whether genes are active or silent has a tremendous impact on what happens in an organism, and decides its physiology.

Besides taking place during development, epigenetic mechanisms are at work during the whole life of an organism (Szyf, McGowan, & Meaney, 2008). It has been suggested that epigenetic mechanisms occur during normal brain activity (Lipsky, 2013), both in youths (Essex et al., 2013) and adults (McEwen, Eiland, Hunter, & Miller, 2012).

Epigenetic mechanisms are dependent on the cell status and consequently its surroundings, i.e., the environment, comprised of both the internal (within the organism)
and the external (outside the organism) environment. This means that the external environment influences the epigenetic mechanisms in the cells. It also means that the genes are not working alone, but are influenced by the environment, and explains e.g., why physical activity influences the cells in the brain. Actually, for the first time we now have a molecular model explaining how the environment could influence gene expressions. This is revolutionary knowledge and why many biologists talk about a paradigm shift in biology (Gilbert & Epel, 2009). This also gives clues to the classical debate about “what-is-due-to-genes” and “what-is-due-to-the-environment.” “Nature versus nurture” is now replaced by “nature and nurture.”

**Figure 1.** Different epigenetic mechanisms: methylated DNA, modifications of histones and micro-RNAs.

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https://www.google.se/search?q=dna+epigenetics&biw=1061&bih=497&source=lnms&tbm=isch&sa=X&sqi=2&ved=0ahUKEwi_5uzdksjLAhUoEJoKHXP9ArIgAUIBigB#imgrc=hg6dMeKdVMKsYM%

Modified by Mc Ewen.

**PHYSICAL ACTIVITY AND LEARNING**

Meta-analyses have shown the positive relationship between physical activity and cognitive performance. Fedewa and Ahn (2013) pointed to significant and positive effects of physical activity on cognitive outcomes in 59 studies performed between 1947 and 2009. Raspberry et al. (2011) showed significant positive associations between physical activity and academic performance in slightly more than half of the 50 investigated studies. However, meta-analyses indicating no significant relationship between aerobic fitness and cognitive
Performance have also been found (Etzier et al., 2006). Thus, there are meta-analyses in the literature pointing to both positive and no effects of physical activity for cognitive performance, but the positive connections are more prevalent. Below, some examples of projects and studies describe the connection between physical activity and improved school results.

The Bunkeflo Project started in 1999 in a school in the southwestern part of Sweden. The curricula contained physical activity for every pupil each day from the first to the ninth grade. Several studies and some theses have been produced in the project. In his thesis, (Fritz, 2017) Fritz showed that 7% more of the boys in grade 9 reached qualification for upper secondary school (for the girls, the daily extra physical activity did not influence their qualification level; a result explained by the girls’ already high academic performance). Similar results were shown in another thesis from the Bunkeflo Project, where Ericsson (2012) presented that 96% of the boys reached qualification for upper secondary school in the intervention group compared to 84% in the control group. For the girls, the figures were 97% and 95%, respectively.

In a study by Käll and colleagues, the odds for achieving the national learning goals in Swedish, English, and mathematics in grade 5 were doubled for children participating in an intervention compared to a control group (Käll et al., 2014). The intervention consisted of an almost double amount of weekly school-based physical activity without changing the ordinary schedule. The extra physical activities were delivered by staff from a local sports club and were designed to be engaging, enjoyable, health promoting, and non-competitive. A meta-study from the U.S. showed that for circa 250,000 children in grades 3-11, fitness was strongly and significantly related to academic performance (Van Dussen et al., 2011). Chomitz et al. (2009) communicated a positive significant relationship between fitness and academic achievement, and Spitzer and Hollmann (2013) described positive effects on academic performance due to physical exercise. Furthermore, Spitzer and Hollmann (2013) informed about a positive effect on concentration and social behavior, besides that of academic performance.

Animal experiments have revealed that physical activity influences the hippocampus, the part of the brain where formation of memory takes place. Gomes da Silva et al. (2012) showed that adolescent rats, exposed to daily treadmill exercises, exhibited a changed hippocampal structure. The rats also displayed improved spatial learning and memory. Herting and Nagel (2012) reported on rodents with a larger hippocampal volume after having increased their aerobic fitness. Thus, animal experiments have shown that the structure of the hippocampus changes due to physical activity, and as the hippocampus is the part of the brain where formation of memory takes place, there seems to be a physiological link between physical activity and learning.

**PHYSICAL ACTIVITY, LEARNING, AND EPIGENETICS**

It would, of course, be interesting to understand more of the mechanisms behind the connection between physical activity and learning, and how this is coupled to that part of the brain, hippocampus, where the memory formation takes place. One conceivable mechanism
is epigenetic processes. Different attempts to answer this question have been performed in various studies. The use of laboratory animals offers one way.

Abel and Rissman (2013) studied laboratory animals (adolescent male mice) running in so-called “running wheels” for one week. Compared to a control group, the epigenetic patterns of the hippocampus were changed in the “running” animals. Similarly, Gomez-Pinilla et al. (2011) showed that voluntary exercise changed rats’ DNA methylation pattern in the hippocampus. Thus, these studies showed that epigenetic patterns in the brains of laboratory animals changed due to physical activity, and that the changes were localized to that part of the brain where memory formation takes place (the hippocampus). Abel and Rissman (2013) speculated about the plausibility that epigenetic patterns could also change in human brains due to physical activity.

Several researchers have suggested the involvement of epigenetic processes during learning and memory formation (Day & Sweatt, 2010; Levenson et al., 2006; Lipsky, 2013; Miller et al., 2010; Molfese, 2011). New synapses between neurons are built during these processes (Cortés-Mendoza et al., 2013). Lipsky (2013) showed that epigenetic processes are important when new synapses are built. Furthermore, epigenetic mechanisms are involved in cellular processes during physical activity. Rönn et al. (2013) reported that within a group of healthy, but untrained, middle-aged men, epigenetic patterns changed in approximately 7,600 genes after a six month physical activity intervention. The activity consisted of two hours of spinning and aerobics each week, and was led by a certified instructor. Other studies have shown that epigenetic mechanisms were observed in the skeletal muscles after an intervention of physical exercise (Barrès et al., 2012; Lindholm et al., 2014; McGee et al., 2009). Accordingly, there is an occurrence of epigenetic processes during both learning and physical exercise. It is also conceivable that epigenetic processes are the mechanism that explains why physical activity supports learning. Future research will bring to light more about these relations.

DISCUSSION

Old masters of learning, e.g., Dewey, Piaget, and Vygotsky have had an enormous impact on our understanding of learning during the last 150 years, and still have. However, their knowledge was based on accessible facts of that time. Due to progress in research, a massive amount of knowledge has accumulated since these days. Whatever view we have on learning, the basis for our knowledge relies on understanding biological processes in our bodies, and particularly in the human brain. Thus, we ought to be aware of what these new findings could result in. When discussing learning, novel findings in brain research is especially important to consider, as well as its ability to build new neurons. It is also of great interest to focus on the newly unraveled epigenetic mechanisms.

A great number of studies have shown that physical activity increases academic performance (Chomitz et al., 2009; Fedewa & Ahn, 2013; Ericsson, 2012; Fritz, 2017; Käll et al., 2014; Raspberry et al., 2011; Spitzer & Hollmann, 2013; Van Dusen et al., 2011). In addition to increased academic performance, a positive effect on concentration and social behavior have
also been reported (Spitzer & Hollmann, 2013). Thus, increasing physical activity in the school timetable seems to be one way to increase academic performance, and also perhaps to promote a more peaceful school atmosphere. There have been some reports of no effects of physical activity on cognitive performance (Etnier et al., 2006), but the positive connections are more prevalent in the literature. Moreover, there are numerous reports about the importance of physical activity for the overall human health (e.g., Berryman, 2010; Lindholm et al., 2014; Rankinen & Bouchard, 2007) in addition to the indicated positive effects of physical activity on academic performance.

A potential mechanism for the connection between physical activity and improved academic performance is the newly unraveled epigenetic mechanisms. These have been discovered in those parts of the brain where memory formation occurs, namely, the hippocampus (Day & Sweatt, 2010; Levenson et al., 2006; Lipsky, 2013; Miller et al., 2010; Molfese, 2011). Animal experiments have shown that increased physical activity changed the epigenetic patterns in the hippocampus, indicating a learning process (Abel & Rissman, 2013; Gomez-Pinilla et al., 2011). It has also been speculated that this takes place in the human brain (Abel & Rissman, 2013). Thus, there seems to be a connection between increased physical activity, learning, and changed epigenetic patterns in the brain.

The observation that physical activity seems to increase academic performance is important. It ought to lead to more discussions about increasing the amount of physical activity in the school timetable. As a complement to current discussions on how to improve school results, perhaps one of the easiest ways could be just to add more physical activities to the school timetable. Some researchers have expressed this in the following way: “In the light of these results, physical exercise should play a bigger role in school children’s daily curriculum” (Spitzer & Hollmann, 2013, p. 1), and “Exercise may prove to be a simple, yet important, method of enhancing those aspects of children’s mental functioning central to cognitive development” (Tomporowski et al., 2008, p. 111). Åberg et al. (2009) wrote: “… physical exercise could be an important instrument for public health initiatives to optimize educational achievements, cognitive performance, as well as disease prevention at the society level” (p. 20906). To summarize, by increasing the amount of physical activity in the school timetable, learning might be facilitated; thus, this is a good example of how to incorporate new knowledge to a practice at school.

CONCLUSIONS

Old masters of learning, such as Dewey, Piaget, and Vygotsky have had an enormous impact on our understanding of learning, but their knowledge was based on accessible facts of that time. This paper points to the importance of following current increasing knowledge in biology when discussing prerequisites for learning. In this study, this is exemplified with the rapidly evolving understanding of brain physiology and new insights into epigenetics. The positive correlation between increased learning and physical activity is highlighted. It is speculated that epigenetic mechanisms could serve as a molecular model to explain this connection. Phrased in a school context, one of the best ways to improve school results could
be to increase the amount of physical activity in the curriculum. This is a good example of how to connect new knowledge about human physiology to practice at school.

REFERENCES


