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Physical Activity and Cognition: Inseparable in the Classroom

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Traditional education has tended to compartmentalize abstract thought, emotion, and physical activity. However, neuroscientific evidence suggests that these are completely interlinked in the learning process. The traditional lecture-style lesson relegates students to a passive and sedentary role, precluding physical movement. In addition, the current trend of schools reducing recess hours, dropping physical education classes, or subjects that involve the whole body—theater, music, outdoor activity—further limits the scope for physical movement within the learning milieu. Neuroscientific evidence suggests that sedentarism impacts negatively on brain health, and not only physical well-being. Humans are designed to be on the move, to interact with their environment through movement: physical activity is a key contributing factor to healthy brain function. This mini review presents and analyzes evidence from diverse studies and meta-analyses showing the strong link between movement and cognition in primary and secondary school students. There is a growing body of neuroscientific evidence of the benefits that movement and physical activity have for cognition. In the research examined, the authors identify diverse types and degrees of physical activity and their impact on the brain. The neurological impact of movement on the brain can be understood at three levels: increased vascularization—oxygen and glucose to the brain—augmenting brain activity; the release of neurotransmitters and Brain Derived Neurotrophic Factor (BDNF) which favor neurogenesis, memory, attention and motivation; and the development of complex movement-related neural circuits and their interconnection with the executive brain functions. This article proposes a set of concrete applications for educators to bring movement into their classrooms and/or learning contexts, thus favoring cognition. Based on this evidence and given the current educational reality which generally approaches learning as an abstract activity divorced from our corporality, the authors argue for the need to incorporate physical activity and movement into the learning context.

Keywords: physical activity, movement, neuroeducation, cognition, BDNF, exercise, neurotransmitters, fitness

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INTRODUCTION

Neuroscientists, such as Immordino-Yang and Damasio, in their paper "We feel therefore we learn" (Immordino-Yang and Damasio, 2007) allude to the need in education for a shift in paradigm from that of Descartes "I think therefore I am"—an aggrandization of rational, abstract thought—toward a paradigm that recognizes the social and emotional components of human cognition. In classrooms around the world there is a growing recognition of the need to incorporate socioemotional learning into pedagogical practice, based on a broader conception of the learner as a "whole person"—a social being with emotions. If classroom practice is beginning to recognize the place of emotion in learning, possibly the next challenge to educators is the recognition of the body as a key element in cognitive development and processing. Teaching and learning cannot focus purely on the brain, to the exclusion of the body. The traditional lecture-style lesson relegates students to a passive and sedentary role, precluding physical movement. The current trend of schools toward reducing time allocated for physical activity, prioritizing instead the focus on academic subjects that feature in standardized tests, exacerbates sedentarism in schoolchildren (Chaddock-Heyman et al., 2018). A 2018 World Health Organization (WHO) report established that "in 2016 almost 340 million children and adolescents (aged 5–19 years) or almost one in every five (18.4%) were overweight or obese globally"—a more than 10-fold increase in the past 4 decades[1]. Moreover, WHO statistics for 2010 revealed that 80% of school-going adolescents were insufficiently physically active[2]. Evidently, this has major health implications, as well as an impact on cognition and academic achievement. Neuroscientific evidence suggests that sedentarism not only hinders learning, but that it flies in the face of how the human anatomy and brain have evolved: from the perspective of evolutionary neurobiology, authors, such as Bramble and Lieberman (2004), Lieberman (2010), and Raichlen and Polk (2013) propose that long distance running and walking molded the human anatomy and brain size. Vorkapic-Ferreira et al. posit that "The evolutionary hypothesis of endurance running states that movement played a crucial role in the emergence of typically human anatomical features, as well as in the shaping and structure of the human brain (...). Effectively, the human body, including the brain, has evolved to withstand extended periods of cardiovascular stress. Movement is so essential to the brain that regular physical activity is imperative for it to function properly. Studies have shown that aerobic exercise increases neuron proliferation, neurotrophic factors synthesis, gliogenesis, synaptogenesis, regulates neurotransmission and neuromodulation systems, and reduce systemic inflammation. All of these effects have a significant impact on improving mental health, reducing age-related gray matter decline, and improving cognitive functions" (Vorkapic-Ferreira et al., 2017). We are designed to be on the move, we interact with our environment through movement: physical activity is the foundation of brain functioning, as asserted by Llinás (2001), Ratey and Hagerman (2008), and Wolpert (2011). Diamond observes that "The same or substantially overlapping brain systems are important for both cognitive and motor functions (Diamond, 2000; Rosenbaum et al., 2001). The brain does not recognize the same sharp division between cognitive and motor function (or cognitive and emotional functioning, or social and emotional functioning, and so on) that we impose in our thinking" (Diamond, 2010).

Neuroscience research over the past 10 years has produced significant evidence that movement and cognition are favorably linked (Diamond, 2000; Cotman and Berchtold, 2002; Hillman et al., 2005, 2009a; Chaddock et al., 2010a; Castelli et al., 2014; Erickson et al., 2015; Mandolesi et al., 2018). Today, a growing body of studies points to the wide-ranging benefits of physical activity for cognition: neurophysiological and neurochemical changes improve brain function, alter brain structure, lead to greater well-being and improve learning. However, some studies produce mixed results—of a neutral, insignificant or negative relationship—and researchers urge the refining of research parameters and greater methodological rigor in order to identify contextual variable/s involved (age-range, intensity, duration or type of exercise, etc.) (Marques et al., 2017). Overall, however, it would appear a relevant challenge for educators to explore how to implement this knowledge of a favorable association between physical activity and cognition, in order to improve the teaching-learning process.

In what ways does physical movement favor cognition? Through increased blood reaching the brain (vascularization), the release of neurochemicals, and neural networks. Referring to a selection of research studies, let us examine each of these: the human brain represents just 2% of human body mass yet it requires 20% of energy consumed (Hart, 1975). With physical activity, blood-flow (vascularization) is augmented, thereby augmenting the oxygen and nutrients reaching the brain, enhancing brain activity (Delp et al., 2001; Hillman et al., 2009b). In the classroom, if teachers simply ask students to stand up and stretch, the brain receives 7% more oxygen (Krock and Hartung, 1992). Thus, by incorporating movement activities into the lesson plan, or inserting brief movement breaks teachers are enhancing brain activity. There are numerous studies on this—to cite a few: research with 9 to 11-years-old showed that 4-min physical activity intervals during class-time improved selective attention, which is crucial for learning (Ma et al., 2015). Another study (Mahar et al., 2006) showed how a daily 10-min movement break ("Energizers") in class improved attention and on-task behavior, and most notably in students who habitually showed "off-task" behavior. In a study on embodied cognition (Kontra et al., 2015), college physics students who physically participated in doing an experiment on the mechanics of movement forces of a bicycle wheel, demonstrated greater activation of sensorimotor regions during learning and during recall, and achieved notably better results than sedentary peers in a test on the subject matter. These sensorimotor circuits are adding kinetic detail and meaning to their thinking (Glenberg, 1997; Barsalou et al., 2003; Zwann and Taylor, 2006; Beilock et al., 2008). Diamond (2010) makes the analogy of driving a car: when do you remember a route better, when you are driving the car, or when you are a passenger? Clearly, when students have an active, multisensorial role in their learning—and increased brain regions are involved—learning is enhanced. Physical activity can be incorporated into lessons themselves, or into the school day. Castelli et al. (2014), in a meta-analysis, explain how including physical activity in lessons yielded improved academic achievement in scores and tests (Ahamed et al., 2007; Donnelly and Lambourne, 2011), and that incorporating vigorous PA into the school day (dance routines, tag, running, PE lessons) improved memory, concentration and academic performance (Carlson et al., 2008; Pesce et al., 2009; Castelli et al., 2011; Gao et al., 2013).

[1]World Health Organization. Retrieved from: https://www.who.int/gho/publications/world_health_statistics/2018/en/ (accessed September 03, 2019).

[2]World Health Organization. Retrieved from: http://apps.who.int/gho/data/view.main.2463ADO?lang=en (accessed September 03, 2019).

Physical activity triggers the release of neurochemicals that favor learning and memory. These neurotransmitters include dopamine, associated with motivation, focus and learning; serotonin which enhances mood, norepinephrine which improves attention, perception and motivation (Basso and Suzuki, 2017). Emotional well-being is vital for learning. When the amygdala in the "emotional brain" or limbic system detects emotional states, such as stress, fear or anger, it is overwhelmed by excessive levels of norepinephrine and dopamine, and "freezes" in an "amygdala hijack" (Goleman, 2005; Willis, 2009), impeding the processing of new information in the hippocampus, i.e., learning is impeded (Willis, 2009). The prefrontal cortex, where higher-order cognitive functions (the executive functions, EF) are concentrated, is also highly vulnerable to stress-related norepinephrine and cortisol release, which lead to prefrontal dysfunction (Birnbaum et al., 1999; Liston et al., 2009). As Lavados (2012) and Mora (2017) observe: we learn what we love, positive emotion smooths the way for learning. Or, to paraphrase Amanda Céspedes—more effective learning requires more affective learning (Céspedes, 2008). Negative emotional states in students effectively hamper learning—and the opposite is true: when teachers are aware of the affective state of their students, and work to cultivate a positive, safe socioemotional classroom environment, learning and memory are enhanced (Diamond, 2010). Thus, when teachers incorporate physical activity into the learning process—with the subsequent release of the abovementioned neurotransmitters they are potentially fostering positive mood states, lowering stress and favoring learning and memory (Willis, 2009; Lavados, 2012).

Furthermore, because movement activities usually include interaction and eye-contact, this stimulates the "social brain," causing the activation of mirror neurons which favor empathy; the release of feel-good endorphins; the social-bonding neurotransmitter oxytocin; and motivational neurotransmitters like dopamine (Rilling et al., 2002; Willis, 2008). Diamond and Ling emphasize that our emotional, social and physical well-being impact heavily on cognition. They explain how EFs are the first to suffer if a subject feels stressed, sad, lonely, not in good physical health and lacks sleep (Diamond and Ling, 2015). Physical exercise combats these damaging states, enabling higher-order cognitive functions (Carmack et al., 1999; Williamson et al., 2001; Haslacher et al., 2015) and improves sleep (Yang et al., 2012; Chen et al., 2015; Wachob and Lorenzi, 2015). Gould points out the 2-fold impact of physical exercise: it reduces stress along with the negative consequences stress has for brain function while it also favors neurogenesis and brain performance (Gould, 2015). Given that students are habitually exposed to stress (the demands of tests, time limits, etc.), physical activity may be playing the role of stress-reducer that consequently improves the brain's capacity for cognitive processing (Mora, 2017). Studies also point to the importance of movement activities being voluntary or joyful (the attitude of the student toward the activity matters): when exercise is collaborative, unthreatening and fun (vs. a boring obligation), brain-function is enhanced (Diamond and Ling, 2015). Ratey and Hagerman present the case study of a high school which integrated motivational, fun, non-competitive physical education sessions into the school day. When the school took the international standards test, Trends in International Mathematics and Science Study (TIMSS) it came out in first place in science and sixth in math in the world—the US average is at eighteenth and nineteenth place (Llinás, 2001). Nevertheless, although this data appears encouraging, it warrants mention that this was a school-wide change in policy on physical activity, not an experiment conducted by a research team. Hence, this evidence, though potentially positive, should be taken with caution, and rigorous follow-up studies would be warranted in order to narrow down variables involved and to clarify the interpretation of results.

The favorable impact of voluntary aerobic exercise on the size and function of the hippocampus (region associated with learning) in rodents has been much studied (Van Praag et al., 2005; Vivar et al., 2013). Voluntary aerobic exercise is an excellent trigger of Brain Derived Neurotrophic Factor (BDNF) which stimulates the growth of new neurons (neurogenesis), new connections between neurons (synaptogenesis) and the protection of existing neural circuits in the hippocampus (Voss et al., 2013; Jeon and Ha, 2015; Basso and Suzuki, 2017) (in older adults it counteracts hippocampal shrinkage Voss et al., 2013—a burgeoning research field, but beyond the scope of this mini review). It is remarkable that PA should cause these structural changes particularly in the part of the brain where learning occurs—and not in the sensorial or motor regions. Ratey explains that it makes evolutionary sense: "… the reason we need an ability to learn is to help us find and obtain and store food. We need fuel to learn, and we need learning to find a source of fuel …" (Ratey and Hagerman, 2008). As posited by Gómez-Pinilla et al., "these findings suggest that BDNF is part of a central mechanism through which physical activity integrates with elements of energy metabolism to impact aspects of hippocampal function. These findings support the evolutionary contention that learning ability is intimately related to energy balance, an attribute that may have developed to maximize motor operations that increased the chances of obtaining food and the probability of survival" (Gómez-Pinilla et al., 2008). Physical activity is effectively "growing the brain" through BDNF release and increased hippocampal size.

Let us consider a few of these structural changes: research demonstrates that individuals who exercise more have greater cortical mass (Anderson et al., 2002). Children who are more physically active have greater volume of gray and white matter: the hippocampus, region of the brain where learnings become stored as memories, is larger in fitter children as are the basal ganglia (Chaddock et al., 2010a,b)—brain structures are associated with learning. These children showed better academic achievement in tasks related with EFs and associative memory (Castelli et al., 2014). Chaddock-Heyman et al. show evidence that children who are more physically active undergo changes in their white matter (corpus callosum)—which integrates cognitive, motor and sensory information between left and right hemispheres (Chaddock-Heyman et al., 2018). Fitter individuals show differences in brain structure and function (Hillman et al., 2009a; Castelli et al., 2014). With regards brain function, studies show greater brain activity, greater connectivity between hippocampus, prefrontal region and cingulate (Chaddock-Heyman et al., 2018) and academic results or cognitive performance can show improvement related with physical activity (Pesce et al., 2009; Chaddock et al., 2010a; Donnelly and Lambourne, 2011; Castelli et al., 2014; Rama Kranthi et al., 2014; Erickson et al., 2015).

A longitudinal study by López-Vicente (the first of this nature) followed 1,400 children from the age of 6 through to their teens. Their conclusions indicated that children with a lower level of physical activity at age 6 showed significantly poorer results in memory tests as adolescents than their fitter peers (López-Vicente et al., 2017). This would appear to imply that greater levels of PA in developing years has long-term cognitive benefits. Research studies by Hillman et al. show how children with higher aerobic-fitness levels showed better neurocognitive function, evidenced in greater attention and working memory levels as well as brain response speed to cognitive tasks (Hillman et al., 2005). Their research also showed that fitter children show better cognitive performance in tasks, demonstrating greater executive control and attentional resources (Hillman et al., 2009a). Sibley and Etnier's metanalysis compiles evidence that PA improves perceptual skills, IQ, achievement, verbal tests, mathematic tests, among others (Sibley and Etnier, 2003). In the abovementioned studies, as in others cited, is important to highlight that causality should not be assumed between the variables, such as fitness level and the different brain functions measured. These results point to a favorable relationship, but the nuances of that relationship, and the other variables involved warrants further exploration.

Neuroscience research is revealing that brain areas are far more interlinked than previously imagined—for example the cerebellum, associated previously with EFs (inhibition and interference control, cognitive flexibility, working memory) (Diamond, 2012) associated with the PFC are intricately connected with multiple other regions—for example, areas related with emotion and physical movement (Diamond, 2000, 2010). Research reveals that the cerebellum, traditionally linked only with motor functions, is also associated with thought, attention, emotions and social skills (Diamond, 2000). The cerebellum is active in cognitive functions, not just motor. The perception that motor development and cognitive development are separate, no longer holds in the face of this evidence. In fact, in both PA and thought processing, there is co-activation of cerebellum and prefrontal cortex. Cerebellar damage impacts on cognitive processing and damage to the PFC impacts on motor functions (Diamond, 2000). Brain circuits involved in physical movement are not completely distinct from those used for thinking, as described by Llinás (2001) "That which we call thinking is the evolutionary internalization of movement". Or, in the words of Ratey—Nature is a frugal creator: when we exercise, particularly with complex, sequenced movements, we are using the same circuits of prediction, sequencing, estimating, planning, rehearsing, self-observation, judgment, mistake correction, shift of tactics, and remembering as we use for thinking processes (Ratey, 2001; Ratey and Hagerman, 2008; Diamond, 2012). But, to what extent are EFs transferrable? Diamond and Ling (2015) in a rigorous meta-analysis analyze this, conclude that EF transfer is narrow (i.e., if working memory is exercised in PA, this EF will transfer to cognitive activity, but other EFs like cognitive flexibility or inhibitory control will not since they were not exercised). Diamond and Ling also noted that individuals with poorest EFs benefit the most, and practice at progressively higher level of difficulty is ideal. They conclude that physical activity which involves cognitive challenges, such as planning, concentration, inhibitory control, cognitive flexibility, working memory (martial arts, team sports, yoga) contributes to improving these EFs in cognitive challenges (Manjunath and Telles, 2001; Lakes and Hoyt, 2004; Diamond, 2012; Chang et al., 2013; Diamond and Ling, 2015). Evidence indicates that "conscious" or mindful PA grows EFs while mindless PA does not (Oswald et al., 2006; Diamond, 2012; Moreau et al., 2015). This evidence supports the growing understanding that physical movement and cognition are intricately intertwined, impacting on and co-activating each other.

At this point, it is vital to highlight the limitations in this area of research. Though the existing literature confirms the favorable association between PA (both for acute and chronic PA) and cognition, several recent meta analyses (Sibley and Etnier, 2003; Lees and Hopkins, 2013; Diamond and Ling, 2015; Tomporowski et al., 2015; Donnelly et al., 2016; Basso and Suzuki, 2017) call for a cautious and critical interpretation of research in this relatively new area. Despite the positive association between PA and cognition, some research studies indicate that this positive impact is relatively minimal and that results are influenced by a multiplicity of factors and differ depending on the duration of the PA intervention, the frequency, whether it is aerobic or not, chronic or acute, the degree of exertion involved, and whether it is mindful or mindless (Donnelly and Lambourne, 2011; Tomporowski et al., 2015; Basso and Suzuki, 2017). There are important caveats to mention with regards the impact of acute (single bout) exercise on the brain and the variability of results of acute and chronic exercise on the brain (Diamond and Ling, 2015; Tomporowski et al., 2015; Basso and Suzuki, 2017). Basso and Suzuki's review of 273 studies concludes that the impact of acute PA is short-lived -and generally observable in improvement in mood, stress-reduction, extended presence of dopamine and serotonin and increased hippocampal activity (Basso and Suzuki, 2017). Regular, long-term, moderate to high intensity exercise with a "qualitative" or cognitive component has a deeper, more long-lasting impact on brain structure, function and neural networks (Diamond and Ling, 2015; Tomporowski et al., 2015). Other studies show that PA does not compromise academic performance—in other words, neither a positive nor negative impact (Ahamed et al., 2007; Resaland et al., 2016; Marques et al., 2017). Another factor of complexity is the type of tool used to measure the impact of PA on cognition (EEG, fMRI, academic performance, cognitive function tests, such as Stroop, Go/Not Go), and what elements are being measured—neurophysiological changes, neurochemical or behavioral changes (Tomporowski et al., 2015; Donnelly et al., 2016). There is a need to standardize variables measured in research on exercise: its duration, intensity, perceived exertion—which Basso and Suzuki propose with their "Exercise Index" (Basso and Suzuki, 2017) in order to understand and relativize research results. Finally, Diamond and Ling (2015) caution that we must be careful of assuming causal relationships: though numerous studies show fitter individuals have stronger cognitive function (for example EFs) this is not necessarily a cause-effect relationship. The abovementioned authors observe that it could be that individuals opt for a more active life because of an existing brain predisposition. There is a call from researchers in the field for the development of standardized measuring tools, the application of extreme rigor in future research, and the use of prudence in how existing results are interpreted and generalizations made (Sibley and Etnier, 2003; Lees and Hopkins, 2013; Diamond and Ling, 2015; Donnelly et al., 2016; Basso and Suzuki, 2017). It is important here to highlight the danger of making sweeping generalizations about PA and cognition, and the promulgation of "neuromyths." A neuromyth is imprecise information about the brain that is popularized (often with underlying commercial interests), leading to practices and beliefs that are not scientifically precise and can even impede or undermine the learning process (Dekker et al., 2012).

This said, the overall conclusions emerging from research on PA and cognition indicate a favorable association. Within the current context where schools promote sedentary habits (Donnelly and Lambourne, 2011), the emerging evidence on the favorable interconnection between PA and cognition should encourage teachers to integrate PA into their lessons, and educational institutions to foster PA through curricular, infrastructural and cultural changes. Around the world different establishments are implementing change—from primary schools to Harvard University. Today, the Internet abounds with practical suggestions and programs, such as those used in many of the abovementioned research studies. By encouraging students to bike or walk to school, safeguarding recess-time and fostering active, fun recess and PE activities, and raising awareness among parents and teachers, schools can move toward a more wholesome and holistic learning experience, where the whole child (socioemotional, cognitive and physical) is engaged. Teachers can integrate movement-based activities at different moments of the day—when lethargy sets in after lunch, when concentration spans are waning, to break the ice, pique curiosity, build group trust, to diminish stress. Apart from the resources suggested in the bibliography[3], when teachers are convinced about not excluding corporality from cognitive processes, they become more attuned to the opportunities that arise for including PA to the benefit of learning. They can start lessons with a stretching activity, organize group work so students need to move, to different stations in the classroom, do rotating poster-work on different walls, organize team activities that involve running up to write/stick the answer on the board, throwing a ball or other object to each other while recalling information, Simon Says, mime, drama, short choreographies, etc. Children (and adults) need to move, and when teachers recognize and honor that need in the classroom, learners become better positioned to enjoy and succeed at learning.

[3] NC Healthy Schools: www.nchealthyschools.org; Be Active North Carolina, Inc: www.beactivenc.org; NC Physical Education for Me: www.ncpe4me.com; NC Health and Wellness Trust Fund: www.fitkidsnc.com; ECU Activity Promotion Lab: www.ecu.edu/cs-hhp/exss/apl.cfm; Action for Healthy Kids: Tools for Schools http://www.actionforhealthykids.org/tools-for-schools/1252-brain-breaks-instant-recess-and-energizers; NC Public Schools www.ncpublicschools.org/curriculum/health; http://www.theteachersguide.com/ClassManagement.htm; http://www.teachervision.fen.com/; http://drwilliampmartin.tripod.com/classm.html.

CONCLUSION

In conclusion, this mini review has attempted to provide a limited overview of a growing body of research supporting the interconnectedness of PA and cognition. Though much research points to a positive association between PA, fitness and cognition, a critical and cautious approach is required, as discussed above. As John Bruer cautioned in 1997, "Brain and education: A Bridge too Far" (Bruer, 1997), educators need to be wary of making sweeping generalizations based on initial research findings or superficial information. Today, educators are witnessing and participating in an important shift in paradigm toward one which conceives of the indivisibility of the social, the emotional and the physical in cognitive processing. This holistic conception of the human being is not novel—the Greeks had a clear idea of the interconnectedness of brain, emotion and body. Current neuroscience research appears to affirm the ideas of major educational thinkers like Vygotsky, Piaget, Freire, Montessori. Their intuition that learning is a social, emotional, interactive, meaningful, physical, co-constructive process is being validated today by neuroscience research. This mini review has examined some key contributions of neuroscience research on the inter-connectedness of PA and cognition, with a view to supporting practical classroom application by educators.

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AD designed and researched the article and wrote the manuscript. AF reviewed the final document.

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