Physical Activity and Physical Exercise and Cognition in Children

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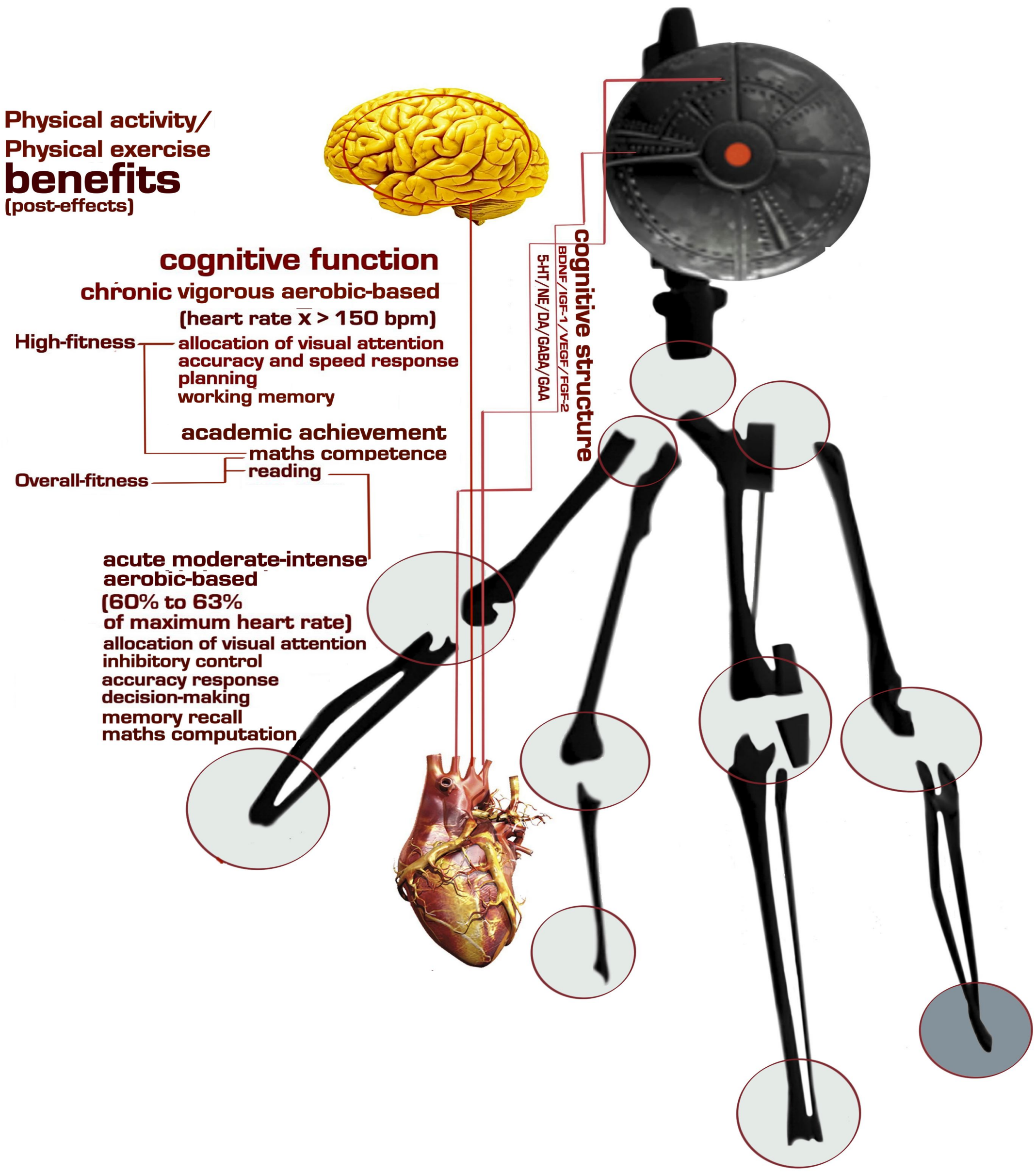

"…there is plentiful evidence that by the time of H. erectus our ancestors had evolved exceptional abilities to run long distances at moderate speeds in hot conditions. The adaptations underlying these abilities helped transform the human body in crucial ways…"

Lieberman (2013:169)

Abstract

Physical activity and physical exercise optimize cognitive function and structure and academic achievement in children. Preadolescent children who engage in chronic physical activity and physical exercise demonstrate improvements in intelligence quotient, social maturity, cognitive function (attention functions; planning) and academic achievement (math competence). Preadolescent children who engage in acute physical activity and physical exercise demonstrate improvements in cognitive function (attention functions; decision-making; memory recall) and academic achievement (reading comprehension). Aerobic-based chronic physical activity and physical exercise performed at vigorous intensities and aerobic-based acute physical activity and physical exercise at moderate-intense levels seem to be the gold standard for improving children's cognitive function.

Physical activity and physical exercise optimize cognitive function and cognitive structure in human adults

Physical activity (PA) is defined as any bodily activity, produced by the skeletal muscles, that requires energy expenditure levels superior to resting (Caspersen et al., 1985; National Institutes of Health, 2013; Welk, 2002; World Health Organization, 2013). PA comprises different subcategories, such as spontaneous PA (informal, unstructured, unorganized and without external guidance; e.g., free play) and organized competitive and noncompetitive PA (formal, scheduled and structured; e.g., sports and physical education classes).

Physical exercise (PE) is a subcategory of PA. It includes planned, structured, repetitive and goal oriented activities whose purpose is the improvement or maintenance of one or more components of physical fitness (e.g., cardiorespiratory fitness) (Caspersen et al., 1985).

PA involves a more complex combination of cognitive skills (e.g., team games evoking immediate and delayed memory) when compared to PE (e.g., aerobic circuit training evoking mostly delayed memory) (e.g. Pesce et al., 2003).

PA impacts multiple systems in the human body: motor system (vestibular system[1]; sensorimotor system); pleasure-and-reward system; attention and memory systems; sympathetic stress response system; circulatory and neurovascular systems (stressing arteries and veins); and immune system. PA allows the immune system to send white blood cells and antibodies through the body at a faster rate; increases body temperature thus preventing bacterial growth; may increase the expelling rate of carcinogens (Cullen, 2012; Jeannerod, 1997; Jensen, 2000).

Aerobic PA and PE[2] have been associated with physiological changes that optimize brain structure and function in adult rats, nonhuman primates and human adults (Barde, 1994; Black et al., 1990; Carro et al., 2001; Cotman & Berchtold, 2002; Davranche & Audiffren, 2004; Ekstrand et al., 2008; Eriksson et al., 1998; Fordyce & Wehner, 1993; Gottchalk, et al., 1999; Kempermann & Gage, 1999; Thomas et al., 2008; Vaan Praag et al., 1999; Zervas et al., 1991). These physiological changes refer to the increased production of neurotransmitters (chemicals) and neurotrophins (protein-like molecules) in the brain.

Neurotransmitters (e.g., serotonin, norepinephrine and dopamine) and neurotrophins (e.g., glutamate, gamma-aminobutyric acid) bind and facilitate the change of information across neurons to generate thought and action (Ratey & Hagerman, 2013).

It is known that aerobic PA and PE increase and balance the levels of 5-HT, NE and DA in the brain. This group of neurotransmitters regulates a great part of brain processes. Aerobic PA and PE also increase levels of neurotrophins (growth factors) (e.g., Gligoroska & Manchevska, 2012; Ratey & Hagerman, 2013).

Serotonin (5-HT) is mainly a mood controller that regulates impulsivity and aggressiveness. Serotonin helps to prevent depression and brain shrinking. Norepinephrine (NE) is essential to processes such as attention, perception and memory (optimizing cognitive function). This neurotransmitter also impacts the levels of

[1] "encodes self-motion information by detecting the motion of the head in space (…) it provides us with our subjective sense of self-motion and orientation thereby playing a vital role in the stabilization of gaze, control of balance and posture" (Cullen, 2012:185).

[2] Involving energetic metabolism that requires the presence of oxygen.

arousal for mood control and boosts motivation. Dopamine (DA) optimizes attention mechanisms, reward-motivated behavior and learning. It also plays a role in motor control and regulation of anxiety.

Both NE and DA are essential for cognitive processing. They have a fundamental role in the prefrontal cortex (PFC) by regulating executive function (Posner, 2004). In addition, NE and DA support emotional regulation (arousal states). 5-HT, NE and DA regulate the levels of glutamate (GAA) and gamma-aminobutyric acid (GABA). While GAA increases neural activity, GABA decreases it.

Neurotrophins relate to Brain-Derived Neurotrophic Factor (BDNF), Insulin-Like Growth Factor (IGF-1), Vascular Endothelial Growth Factor (VEGF) and Fibroblast Growth Factor (FGF-2).

BDNF helps the brain create and maintain its neuronal circuitry. This growth factor protects neuronal cells from dying. Furthermore, it is a molecular element that allows for synaptic plasticity by making neuronal branches grow (neurogenesis; increased number of synapses and axonal branching). BDNF strengthens the affinity between neurons and supports the circuitry of memory (e.g., memory recall) facilitating learning. This element is found in subcortical areas such as the hippocampus (one of the most influent brain areas in memory and learning).

BDNF, as well as other growth factors such as the Insulin-like Growth Factor (IGF-1), Vascular Endothelial Growth Factor (VEGF) and Fibroblast Growth Factor (FGF-2) are released in the brain through blood circulation.

IGF-1 gives support to muscular and brain activity during PE by facilitating catabolic (insulin-like) cellular processes (involved in energetic metabolism). IGF-1 works with the BDNF to facilitate signaling between neurons.

The growth factor VEGF comes into action when the body's running out of oxygen during PE due to increased muscular contraction. VEGF increases the number of capillaries in the brain (facilitating blood fluency in the brain supporting neurogenesis) and body.

The growth factor FGF-2 also increases during PE. It helps tissue growth and strengthens connections between neurons.

Aerobic PA and PE optimize brain structure (binding and growth cellular processes supported by neurotrophins) and function (e.g., attention, perception, memory supported by neurotransmitters), facilitating thought and action. Aerobic PA and PE are associated with increased motivation levels and help reduce anxiety and depressive states (contributing to mental health) (e.g., Gligoroska & Manchevska, 2012; Ratey & Hagerman, 2013).

Moreover, it has been referenced that the nature of motor actions, instilled by contrasting physical environments, affects brain structure in distinctive ways.

Black et al. (1990) demonstrated that PA involving complex motor skills, in physically challenging environments, caused synaptogenesis (formation of synapses between neurons; increased number of synapses per Purkinje cell) in the cerebral cortex of adult rats. The rats interacted with balance beams, see-saws, rope bridges and other obstacles. On the other hand, repetitive formats of PE were associated with angiogenesis (greater density of blood vessels). Rats exposed to a sedentary condition presented no structural alterations in the cerebral cortex.

Ekstrand et al. (2008) verified that PA involving complex motor skills, in physically challenging environments, promoted angiogenesis in the hippocampus and the PFC of adult rats. The rats interacted with e.g., plastic tubes, ladders, ropes (including weekly-modified tasks). On the other hand, freewheel running promoted angiogenesis only in the hippocampus.

Both previous studies demonstrate that PA, involving complex motor skills, in challenging environments, optimizes cortical structure in adult rats (reduced benefits for repetitive PE) and that sedentary conditions do not.

The next subchapter describes the effects of aerobic PA and PE on children's cognitive structure and function.

PHYSICAL ACTIVITY AND PHYSICAL EXERCISE OPTIMIZE COGNITIVE STRUCTURE AND FUNCTION IN CHILDREN

PA has multiple benefits for human development. It benefits the development of the sensorimotor system by stimulating the proprioceptive, vestibular and visual channels (e.g., improves postural and balance control; coordination between body movement and the visual system; optimizes the development of binocular vision and spatial learning); increases motivation and reduces anxiety and depression by raising the levels of serotonin (5-HT), norepinephrine (NE) and dopamine (DA); boosts self-esteem (raising levels of 5-HT and DA); it is associated to the reduction of ADHD symptoms; benefits cognitive function in children with cerebral palsy (Braswell & Rine, 2006; Gallahue & Ozmun, 2005; Jensen, 2000; May-Benson & Cermark, 2007; Montagu, 1972; Payne, 1995; Pellegrini & Smith, 1998; Tantillo et al., 2002; Taylor et al., 1985; Sachs et al., 1984; Verschuren et al., 2007).

The first studies to demonstrate the effects of PA on children's cognitive function were developed in the 1950s and 1960s. These studies evaluated the relation between PA and levels of intelligence through IQ (Intelligence Quotient) tests[3] (e.g., Brown, 1967). This research period suffered a decline between 1970 and 1980 due to growing interest in physical effects associated with PA in detriment of mental effects. Only in the last three decades have we seen a growing interest by the research communities in the relation between PA and cognition, intelligence and academic achievement in children (Kirkendall, 1986; Tomporowski, 2006; Tomporowski et al., 2008).

Recent research suggests that PA and PE optimize cognitive structure/function and academic achievement in children (Brown, 1967; Chaddock et al., 2010ab; Davis et al., 2007, 2011; Ellemberg & St-Louis-Deschênes, 2010; Gabbard & Barton, 1979; Grissom, 2005; Hillman et al., 2005; 2009ab, 2011; Pesce et al., 2009; Tomporowski et al., 2008).

Changes in cognitive structure, happen throughout development, due to genetic and environmental factors (e.g., Black et al., 1998; Gied et al., 1999; Greenough et al., 2002; Huttenlocher, 1979; Huttenlocher & Dabholkar, 1997; Klingberg, 2013; Nelson, 1999; Waber et al., 2007).

Synaptogenesis involves axonal and dendritic growth (including myelination through white matter). Synaptic pruning competes with synaptogenesis to reduce the density of neuronal circuitry. This reduction allows for the establishing of efficient neural networks (circuits), in support of cognition throughout development (e.g., attention, memory and inhibition mechanisms). Both synaptic pruning and synaptogenesis compete for neural growth factors. Growth factors are essential for the formation of synapses between neurons in the nervous system (exuberant synaptogenesis) during early brain development (Huttenlocher, 1979; Huttenlocher & Dabholkar, 1997).

Huttenlocher (1979) conducted a study in order to explain synaptic density changes in the frontal cortex, throughout development. This author evaluated the density of synaptic profiles in layer 3 of the middle frontal gyrus of 21 human subjects (newborn to 90 years of age) – using the phosphotungstic acid method. Accordingly, synaptic density is high during the neonatal period[4], increases to its maximum during infancy (1 to 2 years of age) and declines between ages 2 to 16.

Huttenlocher & Dabholkar (1997) analyzed the formation of synapses between neurons in the auditory cortex and PFC, during the prenatal, neonatal, childhood and adolescence developmental periods. Synapse formation for both cortices starts in the fetus (faster rate in the auditory cortex that reaches is maximum peak by the age of 3 month) and reaches its maximum (in the middle frontline gyrus) approximately by 15 months (exuberant synaptogenesis). Synaptic pruning starts after 15 months (occurring in the auditory cortex until 12-years age) and continues throughout midadolescence (in the PFC).

As referenced before, aerobic PA and PE increase the levels of growth factors in the adult brain. Likewise, aerobic PA and PE tend to increase growth factors in the child's brain - contributing to the development of cognitive structure. In fact, brain development is in great part affected by environmental factors[5] (e.g., Black et al., 1998; Gied et al., 1999; Greenough et al., 2002; Klingberg, 2013; Nelson, 1999; Waber et al., 2007).

Chaddock et al. (2010a) performed neuroimaging studies in order to verify the relation between levels of aerobic fitness and

[3] IQ test is a standard test to measure intelligence. This test measures problem solving abilities, verbal and spatial skills, but not creativity, motivation, socialization, affective skills.

[4] Presenting immature morphologic profiles compared to adults.

[5] Apparently the correlation between genes and I.Q is 0.5 (varying from 0.35 to 0.75) on a scale from 0 to 1 (Plomin & Craig, 2001).

children's cognitive structure and function. They used magnetic resonance imaging (MRI) to investigate the relation between aerobic fitness, hippocampal volume and memory performance (item and relational memory tasks) in a group of 21 high-fit and 28 low-fit children aged 9 to 10 years. High-fit children revealed greater hippocampal volume and memory performance (allocentric spatial relations) compared to low-fit children. The authors concluded that high levels of aerobic fitness optimize cognitive structure and function in the preadolescent brain.

Chaddock et al. (2010b) explored the relation between aerobic fitness and basal ganglia structural volume (subcortical region involved in the control of attention) in preadolescent children. They analyzed dorsal and ventral striatum volumes and attention and inhibition performance in a group of 25 high-fit and 30 low-fit children aged 9 to 10 years - using the Eriksen flanker task. High-fit children revealed a higher volume in the dorsal striatum and better attention and inhibition performance, when compared to low-fit children. No increases in the volume of the ventral striatum were observed. The authors observed that the dorsal striatum seems to be involved in cognitive control of attention and response resolution in preadolescent children. It was concluded that high levels of aerobic fitness improve cognitive control and response resolution in preadolescent children.

The two previous studies demonstrate that high levels of aerobic fitness are associated with improvements in cognitive structure and function in preadolescent children, particularly by increasing hippocampal (improvements in relational memory) and basal ganglia (improvements in cognitive control and response resolution) volumes.

Researchers have found certain formats of PA and PE to be associated with specific improvements in children's cognitive function. For example, PA and PE type (e.g., aerobic or muscular strength), duration (e.g., acute or chronic) and intensity (metabolic levels) seem to influence cognitive function in different ways. Furthermore, effects of PA and PE in cognitive function vary according to developmental levels (Tomporowski et al., 2008; Hillman et al., 2011).

PA and PE programs are classified according to their durability: chronic and acute. Chronic PA and PE imply prolonged periods of activity practice (e.g., weeks or months) in order to alter the physiologic functions and structure of the organism (e.g., cardiorespiratory fitness; muscular strength and endurance). Acute PA and PE imply acute bouts of activity practice (short periods of time) that transiently alter the physiological functions of the organism (e.g., heart rate; stroke volume; cardiac output) (Kenney et al., 2012).

Chronic and acute PA and PE improve children's cognitive function compared to sedentary conditions (physical inactivity; e.g., watching television) (e.g., Brown, 1967; Davis et al., 2007; Ellemberg & St-Louis-Deschênes, 2010; Hillman et al., 2009b; Pesce et al., 2009; Sibley & Etnier, 2003).

Preadolescent children who engage in chronic PA and PE demonstrate improvements in IQ, social maturity, cognitive function and academic achievement. For instance, researchers found a positive association between aerobic-based physical fitness and cognitive function (attention, namely allocation of visual attention, accuracy and speed response) (e.g., Hillman et al., 2005; 2009a; 2011); a positive association between overall physical fitness and academic achievement (Grissom, 2005); a positive association between vigorous aerobic-based PA, requiring complex combination of cognitive skills (e.g., team games, running games, jump rope), and cognitive function (e.g., planning) and academic achievement (math competence) (Davis et al., 2007, 2011).

Preadolescent children who engage in acute PA and PE demonstrate improvements in cognitive function. For instance, better allocation of visual attention, inhibitory control, response accuracy, decision-making and memory recall (immediate and delayed recall). Improvements in concentration, mathematical computation (Ellemberg & St-Louis-Deschênes, 2010; Gabbard & Barton, 1979; Hillman et al., 2009b; Pesce et al., 2009; Schneider et al., 2009) and academic achievement (reading comprehension) were also observed (e.g., Hillman et al., 2009b; 2011; Schneider et al., 2009).

Aerobic-based chronic PA and PE performed at vigorous intensities (heart rate average above 150 beats per minute) and aerobic-based acute PA and PE at moderate-intense levels (60% to 63% of estimated maximum heart rate) seem to be the gold standard for improving cognitive function in children (Davis et al., 2007; 2011;

Hillman et al., 2009b, 2011; Tomporowski et al., 2008).

The next subchapter is a detailed description of the effects of chronic PA and PE on children's cognitive function and academic achievement.

Chronic Physical Activity/Exercise and Cognitive Function and Academic Achievement in Children

Grissom (2005) developed a study in order to investigate the relation between levels of physical fitness and reading and mathematics scores in a group of 88,4715 students (5^{th}, 7^{th} and 9^{th} grades). Levels of physical fitness were evaluated using the FITNESSGRAM® battery of tests - cardiorespiratory capacity, muscular strength, flexibility and body composition. Reading and mathematic scores were evaluated using the Stanford Achievement Test, 9^{th} Edition (a standardized norm-referenced achievement-test). Results indicated that overall fitness correlated positively to academic achievement. This correlation was higher in females and individuals with higher socio-economic status.

Hillman et al. (2005) investigated the relation between age, aerobic fitness and cognitive function in a group of 24 high and low-fit preadolescent children (mean age = 9.6 years) and a group of 27 high and low-fit adults (mean age = 19.3yr). Aerobic fitness levels were evaluated using the FITNESSGRAM® battery of tests. Allocation of attention was measured through electroencephalographic technique, using the P3 event-related potential component - updating of memory after sensory encoding - during a stimulus discrimination task (Oddball task involving visual stimuli). According to the authors, "Adults exhibited faster reaction time than children; however, fitness interacted with age such that high-fit children had faster reaction time than low-fit children" (Hillman et al., 2005: 1967). The authors concluded that aerobic fitness was related to improvements in cognitive function in preadolescent children, particularly in response speed regarding attention allocation mechanisms.

Hillman et al. (2009a) conducted a study in order to evaluate the relation between aerobic fitness and executive control in a group of 38 high and low-fit children (mean age = 9.4). Physical fitness levels were evaluated using the FITNESSGRAM® battery of tests. A modified flanker task (Eriksen flanker task) was used to evaluate levels of inhibitory control. According to the authors, high-fit children "performed more accurately across conditions of the flanker task and following commission errors when compared to lower-fit children, whereas no group differences were observed for reaction time". High-fit children demonstrated better accuracy and thus better executive control (response inhibition) compared to lower-fit children. There were no differences for reaction time in both groups. The authors also referred that the obtained results contrast from those verified in adults "by indicating a general rather than a selective relationship between aerobic fitness and cognition" (Hillman et al., 2009a: 114).

Davis et al. (2007) investigated the effects of chronic aerobic PA on cognitive function in a group of 94 overweight children (aged 7 to 11 years). Children were randomly assigned a 10 to 15 weeks program (5 days a week): no exercise (control group); 20-minutes exercise; or 40-minutes exercise. Physical exercise programs included activities such as running games, soccer, jump rope and modified basketball. These programs were established in order to maintain an average heart rate above 150 beats per minute (corresponding to aerobic-based vigorous exercise). Cognitive function was analyzed at the beginning and at the end of the evaluated programs through the Cognitive Assessment System test (CAS) - attention; planning; nonverbal and verbal spatial reasoning; and processing of sequential information. Results indicated improvements in planning abilities in the 40-min exercise group. It was concluded that continuous periods of vigorous aerobic-based PA improved children's planning abilities, thus supporting executive function for goal-directed behavior.

Davis et al. (2011) performed a neuroscientific study to confirm the results obtained in the previous study. A group of 20 overweight children (aged 7 to 11 years) were randomly assigned a 13 to 14 weeks program (5 days a week): no exercise; 20-minutes exercise; or 40-minutes exercise. Brain activation was analyzed at the beginning and at the end of the evaluated programs through fMRI technique. Results indicated increased bilateral prefrontal activity and reduced bilateral posterior parietal cortex activity in children who were engaged in the 20- and 40-minutes aerobic-based exercise programs. Hence, continuous periods of vigorous aerobic-based PA improved activity in the PFC - brain area is related to executive function.

In a substudy, Davis et al. (2011) investigated the effects of the same 20- and 40-minutes aerobic-based and sedentary programs in academic achievement on a group of 141 overweight children (aged 7 to 11 years). Mathematics and reading abilities were evaluated through the Woodcock-Johnson Tests of Achievement. No academic instruction was provided. The authors reported increased math competence in children who were engaged in the 20- and 40-minutes exercise programs but not in the sedentary condition.

Research has demonstrated that moderate chronic PA is not associated with improvements in academic achievement in healthy children (Tomporowski et al., 2008; Coe et al., 2006). For instance, Coe et al. (2006) verified that physical education classes whose intensity was moderate (approximately 19 minutes of moderate PA) didn't improve grades in middle school children (n=216; six grade students) compared to physical education classes whose intensity was vigorous.

The improving effects of chronic PA in cognitive function have also been found in disabled children. For instance, Brown (1967) developed a study in order to investigate the relation between chronic PA, IQ and social maturity in a group of 40 mentally challenged males (aged 12 years). Participants were randomly assigned two programs: a six-week yoga program requiring postural control and a sedentary program. Participants were evaluated before and after the six weeks period with the Stanford–Binet Intelligence Test and the Vineland Social Maturity Scale. Participants performing the six-week yoga program demonstrated improvements in IQ and social competence. According to the author, postural control engages mental processes such as attention, memory and reasoning, hence, the improvements in IQ in mentally challenged children.

Tomporowski et al. (2008) performed an extensive review of studies investigating the relation between chronic PE and children's cognitive function. Samples included children aged 9 to 14 years. The included activities comprised strength, balance and coordination training, aerobic-based activities and enhanced school PE (excluding sports involving complex combination of cognitive skills). The authors found that vigorous chronic PE tends to improve children's cognitive function, and that moderate chronic PE does not. The researchers also observed that the reviewed studies demonstrated no impact, lower, or robust impact from chronic PE on cognitive function. Tomporowski et al. (2008:11) point out four factors to justify these inconsistent results: "researchers may not have selected tests that are sensitive to the effects of exercise and mental functioning[6]; specific types of exercise training may facilitate cognitive functioning more than others; there are substantial differences among samples of children participating in the reviewed studies; the effect of an exercise intervention may depend on the age, and thus the developmental level, of the children".

Not disregarding the methodological differences that originate a variety of outcomes concerning the effects of chronic PE on cognitive function, recent research points out to improvements in IQ, social maturity, cognitive function and academic achievement in preadolescent children.

The next subchapter is a detailed description of the effects of acute PA and PE on children's cognitive function and academic achievement.

Acute Physical Activity/Exercise and Children's Cognitive Function and Academic Achievement

Hillman et al. (2009b) performed a study in order to investigate the effects of moderate-intense acute aerobic-based PE in cognitive control of attention and academic achievement in a group of 20 preadolescent children (mean age = 9.5). Inhibitory control was evaluated through electroencephalographic technique using the P3 event-related potential component in a modified Eriksen flanker task (involving visual stimuli). Reading comprehension, spelling and math's performance was evaluated using the Wide Range Achievement Test (WRAT3; Wide Range, Inc., Wilmington, DE). Children performed two sessions: a resting session of 20 minutes followed by cognitive testing and evaluation of aerobic fitness levels; a walking exercise session of 20 minutes on a treadmill, at 60% of the estimated maximum heart rate (moderate-intense aerobic PE; 125 heart beats

6 . For instance, IQ tests evaluating general mental competence are less sensitive to the detection of specific cognitive processes (e.g., attention, perception, working memory, etc.) than research methods involving evaluations with closest proximity to the molecular level (e.g., brain imaging) (Tomporowski, 2008).

per minute average), followed by cognitive testing (when heart rate levels returned to 10% of pre-exercise levels). Sessions were counterbalanced. Children revealed improvements in response accuracy and larger P3 amplitude after the exercise session compared to the resting session. Furthermore, children revealed a better academic performance (reading comprehension) after the aerobic exercise session. According to the authors, spelling and maths performance didn´t improve, possibly due to fact that these abilities were evaluated one hour after the end of the exercise session. The researchers concluded that acute bouts of moderate-intense aerobic-based PE improved cognitive control of attention and academic performance in preadolescent children.

Ellemberg & St-Louis-Deschênes (2010) developed a study in order to verify the effects of moderate acute aerobic-based PE on executive cognitive control in different developmental stages. A group of 72 preadolescent boys aged 7 and 10 years (n=36 per age group) was evaluated before and following exercise with two cognitive tasks: simple reaction time (press a button, as fast as possible, so as to identify geometrical forms on a screen); choice response time to visual stimuli (press a button as fast as possible to differentiate a visual circle from other geometrical forms; evaluating decision-making and inhibitory control). Half of the sample performed a 40-minutes aerobic PE program in a cycle ergometer (5 minutes warm-up followed by 30-minutes on a cycle ergometer and cool-down) at moderate intensity (63% of the maximum heart rate corresponding to an average of 132 to 134 heart beats per minute). The other half watched television during 40 minutes. Evaluations were performed immediately after the exercise and TV sessions. Children performing the exercise session performed better in both tasks (significant advantage for the choice response time task) demonstrating improvements in executive control (decision-making and inhibitory control) compared to children who watched television. The researchers concluded that acute aerobic-based PE, at moderate intensities, was related to improvements in executive control in preadolescent children.

Gabbard & Barton (1979) studied the effects of acute PE on cognitive function (mathematical computation) in a group of 106 second-grade children. Children were evaluated in a 2-minute mathematical test before and after performing 20, 30, 40, or 50-minutes of PE in a physical education class. The authors verified increased improvement in mathematical computation skills in the 50-minutes PE condition when compared to the 20, 30, or 40-minutes PE conditions. No significant differences between genders were found. The authors observed that increased duration in PE seems to be associated to improvements in cognitive function, particularly mathematical computation in preadolescent children.

Pesce et al. (2009) investigated the effects of moderate-intense acute PE and PA on memory performance in a group of 52 preadolescent children aged 11 to 12 years. Free-recall memory of visual items (list of twenty words printed on paper) was evaluated in three different sessions: each child was evaluated immediately (immediate recall) and 12 minutes after (delayed recall) engaging in aerobic circuit training in a physical education class (individual session involving instruction); each child was evaluated immediately and 12 minutes after engaging in team games in a physical education class (involving 54% of group interaction; autonomous use and repletion of motor skills in a competitive setting; low levels of instruction); each child was evaluated in a baseline session with no physical exercise. Heart rate values were checked using heart rate monitoring (sub-maximal levels; superior to 139 beats per minute) in both exercise sessions. Researchers hypothesized that the session corresponding to aerobic circuit training would imply less cognitive demands than the session involving team games. Perceived effort was also evaluated. Children in the baseline session had decreased performance in immediate recall compared to children engaged in team games. Delayed recall was improved in children engaged in aerobic circuit training and team games. Accordingly to the authors, "Given the specific characteristics of team game activities, their short-term effect on memory performance may be mediated, at least at preadolescent age, by factors different from the mere modulation of physiological arousal levels. Presumably, the observed short-term facilitation of memory performance after the team game is attributable to the cognitive activation induced by open skill activities characterized by rapidly changing interactive situations and by a corresponding need to carry out perceptual, memory and decisional processes under time pressure". Hence, team games seem to imply increased "cognitive activation induced by cognitive exercise demands". In fact, "cognitively low-demanding exercise tasks (isometric contractions, cycling)" were associated to improvements on delayed recall performance but not on immediate recall performance. In this way, memory recall in preadolescent children was not only affected by levels physiologic arousal but also by cognitive exercise demands.

Schneider et al. (2009) evaluated the effects of a single bout of aerobic-based PE in cognitive function and academic achievement in a group of 11 preadolescent children aged 9 to 10 years. Electrocortical activity was evaluated through low-resolution brain electromagnetic tomography, in the alpha (7.5-12.5Hz) and beta (12.5-35Hz) frequency ranges, before and after a 15-minutes single bout of moderate aerobic-based PE (in a stationary bike). Participants demonstrated increases in alpha activity in the precuneus after exercise; decreases in beta activity in the left-temporal areas (including Wernicke's area) after exercise. The authors observed that an "overall state of physical relaxation after exercise is reflected by a more synchronized state in the precuneus", revealing increases in concentration and cognitive function after exercise (Schneider et al., 2009: 131). Increases in academic achievement post-exercise were also observed. The authors stated that the achieved results seem to be associated with neuroplasticity in "regions relevant for language processing" (Schneider et al., 2009:131).

Hillman et al. (2011) performed an extensive review of studies investigating the effects of acute PA and PE, using neuroelectric measures of brain health and cognition, in preadolescent children. Accordingly, results "differ based on participants' age, exercise duration, modes of exercise and cognitive requirements of the task. However, given the relatively small literature-base, a detailed understanding of this relationship remains unclear in children (…) these findings need to guide future investigations in children to best determine the complex relationship between single bouts of exercise and cognition" (Hillman et al., 2011: S26-27).

The illustration depicted on the first page of this article summarizes the effects of chronic and acute PA and PE in children's cognitive function and academic achievement.

CONCLUSIONS

In this work we demonstrated how physical activity and physical exercise affect children's cognitive function and structure:

- Aerobic physical activity and physical exercise seem to contribute to the development of cognitive structure and improve cognitive function;
- Preadolescent children who engage in chronic PA and PE demonstrate improvements in intelligence quotient, social maturity, cognitive function (allocation of visual attention, accuracy and speed response; planning) and academic achievement (math and reading competence);
- Preadolescent children who engage in acute PA and PE demonstrate improvements in cognitive function (allocation of visual attention; inhibitory control; response accuracy; decision-making; memory recall) and academic achievement (reading comprehension);
- Aerobic-based chronic PA and PE performed at vigorous intensities (heart rate average above 150 beats per minute) and aerobic-based acute PA and PE at moderate-intense levels (60% to 63% of estimated maximum heart rate) seem to be the gold standard for improving cognitive function in children.

FUTURE WORK

There has been a large investment in research concerning the physiological effects of chronic and acute PA and PE in cognitive function and academic achievement in children (post-activity evaluations). Nonetheless, it seems that cognitive function and academic achievement are also affected by the nature of sensorimotor experiences in the environment. In future work we will demonstrate the effects of sensorimotor experiences on children's cognitive function and academic achievement.

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