Chapter 14

Physical Activity, Aerobic Fitness and Academic Achievement

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Additional information is available at the end of the chapter

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Abstract

There is a growing body of literature investigating the relationship between physical activity (PA) and cardiorespiratory fitness (CRF) with academic achievement (AA). This chapter presents new evidence on the relationship between PA, CRF and AA. Studies have shown no association or inconsistent association between objectively measured PA and AA. Nonetheless, despite inconsistent results, it may be concluded that, at a minimum, PA is not detrimental to AA. In comparison, results from studies employing self-reported PA have shown a positive association with AA. The results of these studies are more consistent with reports stemming from many different countries across the world. Similarly, CRF has also evidenced a positive association with AA, suggesting that increasing CRF is important for children and adolescents' health, and further cognitive development and AA. Thus, promoting PA and improving CRF are important for maximizing children and adolescents' health and AA. Because students spend much of their daily lives in school, school-based PA may result in improvements in AA.

Keywords: education, school-age children, academic performance, exercise

1. Introduction

Education is an elementary human right and an important factor of development. In most countries, school education is mandatory to ensure that children gain knowledge and competence to prepare for autonomous living in adulthood. Education must facilitate a healthy process, which includes preparation in the development of physical, cognitive and social abilities. Although education is of importance, merely being school-educated may not be enough for success. In an increasingly competitive society, it is important to have an early foundation for academic achievement (AA). AA is strongly linked with positive outcomes that are valued by society, such as being admitted to university, stable and upwardly mobile employment and steady income. AA can be defined as the extent to which students achieved their short- or long-term outcomes. In school systems, AA is related with the acquisition of knowledge and competences in several or particular domains, such as literacy, science, numeracy, history, language, or even physical, among others.

Because AA is important, it is necessary to understand the factors that may relate and modify it. Among these factors are a complex interaction of socioeconomic status, family education, parental involvement and several other socio-demographic factors [1]. In spite of the complex interaction, health is an important moderating factor in students' capacity for learning and AA [2]. Healthy students learn better and several studies have supported that health behaviors are closely related with AA [3, 4]. Therefore, improving students' health has the potential to improve AA.

Health is associated with physical activity (PA) and cardiorespiratory fitness (CRF) [5]. Regular practice of PA and a healthy CRF in school-age children are associated with health benefits, including improved bone mineral density, cardiovascular risk profiles, cardiorespiratory and muscular fitness, mental and brain health and body composition [5]. In addition to the benefits on physical and mental health, studies in neuroscience have shown that PA and CRF are also related to brain structure and function, via thickness of gray matter in specific cortical regions and integrity of white matter tracts that support executive function [6], and through alterations in brain plasticity that change the structure of the neuron and strengthening its signaling capability [7]. PA and CRF also contribute to improve attention, memory and learning [8]. Accordingly, it is expected that this positive role of PA and CRF on brain structure, function, plasticity and cognition might translate to an improvement in AA [6].

Because of the importance of school education and AA in society, policy-makers and school administrators have increasingly eliminated opportunities for PA in order to make additional time available for formal didactic topics [9]. In reaction, researchers have investigated the relationship between PA, CRF and AA, based on the premise that PA and CRF are beneficial, or at the very least are not harmful, to AA. The research addressing PA and AA dates back to at least 1967, when researchers began studying the relationship between PA and AA in school-age children [10]. Since then, a growing body of literature has examined the relationship between PA and CRF with AA in children and adolescents [11, 12]. The aim of this chapter is to present new evidence of the relationship between PA, CRF and AA; as well as a basic understanding of the potential mechanisms underlying the relationship between health factors such as PA and CRF with learning and AA.

2. Physical activity and academic achievement

PA is a complex behavior that can be defined as any bodily movement produced by skeletal muscles that requires energy expenditure [13]. As a complex behavior, there are several methods to assess PA. The most common are objective measures and self-report measures.

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In the process of PA data collection, self-reported measures tend to overestimate PA when compared with objective measures. On the other hand, objective measures fail to fully capture children's PA, and might not characterize the movement patterns of some activities [14]. As such, it is recommended that researchers are aware that PA values are often considerably different, and therefore the two different methodologies should be considered different constructs. Thus, by separating investigations of objectively measured PA and self-reported PA, associations with AA may be better understood and clarified.

2.1. Objectively measured physical activity and academic achievement

Most people, especially young people, are unable to reliably assess their PA levels [15]. Thus, the use of electronic devices to measure PA is prevailing the use of self-reported questionnaires and diaries. Among the electronic devices to objectively measure PA, pedometers and accelerometers are now widely used within the research community to conduct population-level studies to assess health and performance (note that these devices are also widely used by the general population given their integration into smart phones and watches). Such devices allow for accurate data collection in the research setting without the risk of self-report bias, but they lack the ability to provide information of the type or context of PA. For studies of the relationship between PA and AA, researchers have mainly favored accelerometers to develop a more complete picture of PA in the participant's normal environment [4, 16–18].

In the United States, LeBlanc et al. [19] carried out a study aimed at investigating whether PA, adiposity and AA were correlated. They reported that neither moderate-to-vigorous PA nor sedentary time were associated with AA across different academic courses. Other research by Lambourne et al. [20] with younger students evaluated how objective PA and CRF were related to AA. This study improved upon limitations of previous research by controlling demographic factors including socioeconomic variables and accounting for separate measures of PA and CRF. Neither PA nor CRF were associated directly with reading and spelling performance. However, PA was directly associated with mathematics achievement, as well as indirectly through CRF. This observation is consistent with research on the relation between PA and CRF as well as on the relation between CRF, cognitive function and AA [21]. A third study in the United States, aimed at evaluating linear or non-linear relations between PA/CRF and AA in three academic subject areas concluded that objective PA was not significantly correlated with AA, as described by linear or non-linear trajectories [16].

Results of studies from other countries further show no association or inconsistent associations between PA and AA. For example, a study with adolescent students in Sweden concluded that vigorous PA was associated with AA in girls, but not in boys [22]. This study suggests that there is a threshold level of PA required to produce positive effects on AA, and that higher levels of intensity meet this threshold. In Finland, a study that examined associations between objectively measured and self-reported PA observed that objectively measured PA is not associated with students' AA [23]. In Netherlands, another study provided null results [24]. Overall, no significant association was observed between objectively measure PA and AA.

More recently, similar results were observed by Pindus et al. [17] in the United States. No significant associations were found between moderate-to-vigorous PA and aspects of cognition that assessed inhibition and working memory, or AA. Furthermore, adjustments for CRF did not moderate the association between PA and either cognitive or AA outcomes. In Australia, Maher et al. [18] observed that AA was largely unrelated with moderate-to-vigorous PA, even when the analysis adjusted for potentially confounding socio-demographic factors. A weak but positive relationship was observed in specific domains of writing and numeracy. However, greater amounts of sedentary time were consistently, and more strongly, related to higher AA.

Apart from these results that have indicated null associations between objective PA and AA, there are several studies that suggest otherwise. Specifically, an intervention study in the United States, aimed at evaluating whether implementing curricular PA positively influenced students' reading and mathematics achievement noted that objectively measured PA enhanced cognitive outcomes [25]. Curricular PA had a positive effect on students' reading and mathematics scores. Results from the Avon Longitudinal Study of Parents and Children found that higher amounts of moderate-to-vigorous PA at 11 years old was associated with better AA across academic subjects at 13 and 16 years [26]. Given that most of the PA was characterized as light intensity, when considered in the analysis, higher intensity PA contributed to increased AA.

Perhaps the absence of a relationship between objectively measured PA and AA observed in many studies may be related with the fact that researchers do not distinguish between PA intensity levels. Most studies that failed to find a significant relationship did not separate moderate-to-vigorous PA, instead favoring total volume of PA regardless of intensity level [17, 18, 23, 24]. Furthermore, the inconsistency of findings in studies may also be explained by the procedures used to assess accelerometer data. For instance, PA was measured during seven consecutive days by Syvaoja et al. [23], whereas LeBlanc et al. [19] and Kwak et al. [22] measured PA for 3 and 4 days, respectively. Nonetheless, despite inconsistencies among studies, it can be concluded that PA is not detrimental to AA, suggesting that time spent engaged in PA does not detract from academic outcomes.

Summary: Results from literature showed inconsistent results for objectively measured PA. Thus, the relationship between objectively measured PA and AA is not yet conclusive, although it is generally accepted.

2.2. Self-report physical activity and academic achievement

Self-report PA is an indirect form of assessing PA, requiring individuals to subjectively recall their behaviors via structured interviews, journals or various (more structured) questionnaires. Most studies that examined the relationship between PA and AA used questionnaires, which is the most popular self-report method. However, although objective measures are more reliable [14], the devices to assess PA only capture the movement. Self-report instruments can capture the context and the behavior, which may be important to understand the complexity of PA behavior.

Similar to the general relationship observed between objectively measure PA and AA, there are some studies that did not report significant relationship between subjective PA and AA. For example, a study from the United Kingdom failed to observe a correlation between participation in PA and AA in secondary school students [27]. The authors recommended additional emphasis upon external factors, such as age, sex and type of school, since these factors might play a mediating role in the relationship. However, in an investigation with students from Hong Kong, a place in which AA and success are strongly emphasized, PA level was related neither to school conduct nor AA [28]. This study was particularly interested in understanding the role of gender in the relation of PA on AA. Boys with a higher level of PA demonstrated slightly lower school conduct grades, while more active girls received markedly poorer conduct grades. Culturally, physically active girls are seen as less well-behaved students than corresponding active boys [28]. However, despite PA being culturally related to negative school conduct, it did not affect AA. Two other studies, from Finland [29] and Iran [30] also demonstrated that self-reported PA engagement was not related to AA.

Although some studies demonstrate a null association between PA and AA, most studies that use self-reported PA have shown a positive association. The results of these studies are consistent and it is important to mention that the findings are disseminated from different countries, including Australia [31], Iceland [32], the United States [33, 34], Spain [35], South Korea [36], Finland [23, 37], Chile [38, 39] and China [40].

Most studies that analyze the association between PA and AA have employed cross-sectional designs, and as such causality of the observed relationships cannot be concluded. Therefore, researchers have recommended longitudinal studies to clarify the relationship between PA and AA [23]. One study, in the United States, was designed to determine the contribution of PA to AA from kindergarten to fifth grade [34]. Results showed that parent reported PA engagement of their children was significantly related with better AA among boys and girls. In another longitudinal study between third and fifth grades in Finland, Haapala et al. [37] observed that higher levels of PA during recess and physically active school transportation were associated with better reading fluency, and engagement in any organized sport was related to better arithmetic skills. Such findings suggest that certain types of PA improve AA among children. Furthermore, Haapala et al. [37] was the first study to reveal the direct association of PA during recess with AA. Nevertheless, the results of earlier studies suggest that PA during recess enhances attention, concentration and on-task behavior, which may improve AA in students [12]. The fact that PA was self-reported was helpful to acknowledge the context in which the PA occurs.

Although PA is positively related with AA in most studies [4], it is possible that too much time spent in PA may compete with homework time, becoming detrimental for AA. This was demonstrated in two different studies [23, 35]. Morales et al. [35], with a sample of Spanish students, observed a significant linear correlation between PA and AA. Results from a second-order polynomial regression showed that a certain amount of weekly PA might prove optimal for AA. More than the optimal amount may decrease AA. Results from a Korean study demonstrate that PA was positively correlated with AA; however, when students engaged in five or more times/week of PA the correlation was reversed [36]. A similar curvilinear relationship between PA and AA was also demonstrated by Syvaoja et al. [23] in Finnish students. These results indicated that PA was positively related with AA, but some of the most active children spent time in PA at the expense of time devoted to homework, and thus having a negative effect on AA. It seems clear that for some students there is a trade-off between time spent engaged in PA and other activities more directly related to AA. Those activities may include doing homework and participating in extra-curricular activities.

The importance of intensity is also highlighted in self-reported PA research, similar to studies of objectively measured PA [22, 26]. PA enhanced AA, but higher measures of AA were observed for vigorous PA and team sports [33, 36]. Besides those findings, two studies from Chile showed that students who reported ≤2 h/week of PA had significantly lower AA than those reporting ≥4 h/week [38, 39]. Despite the results supporting the importance of higher PA intensity for AA, there is also evidence, at least in some contexts, that minimal-intensity PA, such as walking, is positively associated with AA [40].

Although there are studies that suggest a certain threshold of intensity [22, 26, 33, 36, 40] or time required for PA to have a productive effect on AA [38, 39], it is important to bear in mind that the main aims of PA promotion are to improve health and prevent chronic disease [41]. Improving AA should be considered among these outcomes. Thus, interpretations of dose-response relationship between PA and AA can be extremely complex because of the several factors that affect students' AA [38].

Summary: In general, studies report positive associations for the relationship between self-reported PA and AA. Results demonstrate that PA and AA have a curvilinear relationship. The most active children and adolescents sometimes practice PA at the expense of time devoted to homework, having a negative relationship with AA.

2.3. School-based physical activity and academic achievement

Even though the benefits of PA for children's health and the importance of physical education (PE) in increasing PA are well established, the allocation of PE time has been diminishing in recent years across several countries [9]. The reduction in PE time is mostly due to the pressures placed on children, parents and school administrators to improve AA, because there is a perception that time spent on non-academic courses, such as PE, has a negative impact on the children's AA [42]. Thus, the allocation of time toward PE and other PA opportunities in the school settings are being replaced with additional academic time in an effort to increase children's AA. Despite this trend, there is no evidence to indicate that AA improves if children's PA opportunities are minimized. In fact, there is a growing body of research focused on the association between school-based PA, including PE, and AA among school-aged youth [12, 43].

Results of cross-sectional studies support a beneficial relationship between PE or school-based PA and AA [44–46]. Such findings suggest that having more PE classes per week might positively correlate with AA. However, there are also findings that did not demonstrate any correlation between school-based PA and AA [47]. Although the results from this study were not significant, it is noteworthy that time spent in PE class did not negatively affect AA.

Two longitudinal studies, aimed at examined the association between time spent in PE and AA followed children for 5 years [34, 48]. The results of these studies were inconsistent regarding

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the relationship between PE and AA. Carlson et al. [48] observed that girls with the highest exposure to PE (70–300 min/week), compared to those with the lowest exposure (0–35 min/week), showed benefits in AA. However, no association was observed between PE and AA among boys. Alternatively, in another investigation [34], PE was not significantly related to AA. It seems that PE as it is implemented in schools does not improve or impair AA. It may be related with the amount of time that students engage in PA, and the PA intensity in PE classes. Usually students' spend less than 50% of the class in moderate-to-vigorous PA in classes [49].

From intervention studies, a significant beneficial effect of PE or school-based PA on AA was observed [50–53]. Increasing the number and intensity of PE sessions had a positive effect on AA [50]. Two additional PA sessions designed to be engaging, enjoyable, health promoting and non-competitive improved children's AA [51], and two high intensity interval training sessions also improve cognitive and mental health among students [52]. In other interventions, no significant effect of the intervention was observed on AA [47, 54, 55]. About 10–15 min of class time devoted to PA, 90 min/week of active educational lessons or 55 min/week of PA across the curriculum did not increase AA, but also did not compromise it either [54, 55].

The positive association between PE and AA is of importance, because the reduction of PE time that has been observed [9], and the argument to support the decision to reduce PE time, is mostly based on the erroneous belief that reducing PE and increasing the other disciplines' allocation time will improve the students' AA. Although some studies did not show a significant association between school-based PA time and AA [34, 54], these studies indicated that PE and school-based PA did not significantly detract from AA.

In sum, there is evidence of a positive relationship of PE and school-based PA with AA. There is also evidence that increasing PE or school-based PA time had no deleterious effect on students' AA. Considering that education to foster AA typically takes place in sedentary environments, children spend a large amount of time sitting in classrooms to receive their education. This traditional learning model contributes to the reduction of PA opportunities at school. However, because PE and school-based PA may positively affect learning and AA, and may impact positively on many other important health outcomes (e.g. quality of life and body composition), there is a need to increase PA time at school. The increase in PA may contribute to improve AA and, naturally, will be important for enhancing children's PA levels, which is important for overall health and function.

Summary: In general, results from the literature suggest that PE and school-based PA are positively related to AA. Increased time spent in PE does not detract from AA even when less time is devoted to academic subject matter in favor of PA. PA breaks during standard classroom instruction also have favorable associations with attention, concentration, academic behaviors and AA.

2.4. Inconsistency between self-report and objectively measured physical activity

Overall, the observed results demonstrate a positive association between self-reported PA and AA across most studies, which is consistent with previous literature reviews in which most studies assessed PA through self-reported questionnaires [11, 56]. However, several studies that objectively measured PA showed no relationship with AA. Perhaps the inconsistency between subjective and objective measures of PA in association with AA may be due to the difficulty of estimating one's overall PA. Objective measures may fail to fully capture children's PA, and might not characterize the movement patterns of some children. Self-reported PA may include activities such as skateboarding or water sports (e.g. body boarding or surfing), which are skill-specific PA related with agility, balance, control and coordination and that do not accumulate activity counts. Therefore, objective and self-reported measures may reflect different constructs or context of PA.

Considering that self-reported PA could include some activities that may not be quantified when using objective instruments (e.g. water activities and skateboarding), and that evidence exists to suggest an association between self-reported PA and AA, it is expected that these types of activities may have a positive impact on students' cognition. This is a plausible argument because some activities that do not accumulate activity counts improve motor control. Motor control development enables children to engage in various postures and activities providing opportunities to interact with the environment and rehearse language and cognitive skills [57]. Children with better motor control performance have better AA [29, 57]. This is consistent with results that demonstrate interwoven associations between motor control and cognitive development, showing that many brain areas are involved in both motor control and cognitive processes [58].

Based on the inconsistent results observed for the objective and self-reported PA, it is clear that the relationship between PA and AA despite being generally accepted is not yet conclusive [11, 56]. It is worth to reinforce that self-reported PA methods possess several limitations in terms of reliability and validity [15]. Self-reported PA can be considered problematic in children and adolescents because they are less time-conscious than adults and tend to engage in PA characterized by sporadic periods with different intensities rather than consistent engagement patterns. Besides compromised reliability, the validity of self-reported PA measures may be affected in children and adolescents who feel compelled to respond in a socially desirable manner. As a result, to report that PA is associated with AA based mainly on self-reported PA should be done with caution; and the assumption that participation in PA positively affects AA or the way that children think and learn in school has yet to be validated [4].

Summary: The inconsistency between subjective and objective measures of PA in association with AA may be due to the difficulty of estimating one's overall PA. Considering that self-reported PA could include some activities that may not be quantified when using objective instruments (e.g. water activities and skateboarding), and that there is evidence suggesting an association between self-reported PA and AA, it is expected that these types of activities may have a positive relationship with students' cognition.

3. Cardiorespiratory fitness and academic achievement

CRF can be defined as the ability of the circulatory and respiratory systems to supply oxygen to skeletal muscles during sustained PA. Regular practice of PA is important to maintain or improve CRF. Although CRF is determined by non-modifiable factors such as growth, maturation, sex, age and heredity, it is also influenced by moderate-to-vigorous PA and sedentary

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time [59]. Despite genetic contributions to CRF, high levels of PA are related with better CRF, which means that PA and CRF are intimately linked.

The relationship between fitness and cognition was first established in children in the 1950s [60]; nonetheless, evidence of fitness benefits on human cognition has been most developed in adults. In recent years, there has been an increase of studies on children and adolescents, mostly related with CRF and students' performance at school. Different from the inconclusive results observed between objectively measured PA and AA, most studies have found that CRF has a significant positive association with AA, suggesting that increasing CRF is important for adolescents' cognitive development and consequently AA [8].

In the United States, Castelli et al. [61] found that physical fitness was generally associated with AA, and in particular CRF was associated with AA in students from grades 3 and 5. Similar results were observed by other authors [62, 63]. Two studies performed with huge samples of Texas students corroborate previous observations, demonstrating a positive association between CRF and AA [64, 65]. Even when analyses were adjusted for potential confounders, the results remained significant [64, 65]. Linear modeling suggested a 5% increase in the prevalence of students meeting healthy body mass index and CRF standards would result in a 2.3 and 0.7% increase in the prevalence of students meeting the Texas Assessment of Knowledge and Skills standard [64]. Using a large sample of students in grades 2 and 3, Hansen et al. [16] found that CRF had a significant quadratic association with both spelling and math achievement. This finding suggests that increasing CRF may have a greater impact on spelling and math achievement for children below a particular fitness threshold than on those above. This further suggests that future research should evaluate the potential benefits of improving CRF for AA among students classified in lower fitness percentiles. More recently, the relationship between cardiovascular and muscular fitness with working memory and AA was investigated in preadolescent children [66]. Results from this study replicated previous findings, showing that mathematic achievement of algebraic functions was associated with CRF. Given that development of childhood CRF has become emphasized, these data suggest that activities targeting improvement of cardiovascular and muscular fitness should be integrated into school- and community-based programs for enhancing students' cognitive health.

Studies from other countries have also demonstrated a positive relationship between CRF and AA. A study carried out with an urban South African group of primary school children observed a positive relationship between CRF and AA, with more significant correlations found among girls than boys, and among older compared to younger boys and girls [67]. This is the only study from an African country, meaning that there is a need of more studies to understand the role of CRF in AA in this particular context. Nevertheless, based on this study, advocating the enhancement of physical fitness levels of children by promoting PA is necessary.

Evidence from European countries also supports the importance of physical fitness, particularly CRF, for students' AA. In the Netherlands, Greeff et al. [68] found a positive association between CRF, spelling and mathematics performance in non-socioeconomic disadvantage students; and between CRF and mathematics for socioeconomic disadvantage students. This finding is important to understand the importance of CRF on students' learning, regardless of their socioeconomic status. In Spain, it was observed that CRF was associated with AA, and the significant association remains even after adjustment for fitness and body composition indicators [69]. In Portugal, the relationship between CRF and body weight status on AA was investigated among seventh-grade students from different cohorts [70]. CRF and weight status were independently and synergistically related to AA, independent of the different cohorts. This finding provides further support that CRF and healthy weight students are more likely to have better performance at school.

Although the evidence of the positive relationship between CRF and AA seems to be overwhelming, results from the presented studies need to be interpreted with caution, since the cross-sectional design can only suggest an association between the variables, rather than provide causal inference. Thus, longitudinal studies are needed to clarify the association. So far, there are not many longitudinal studies that analyzed the effect of CRF on AA.

However, recent research assessed potential differences in AA based on CRF over a 2-year period, and found that students who maintained a healthy CRF had the highest mean scores in AA tests [71]. Those who had the lowest scores were not in the healthy zone for CRF in grades 5 and 7. These suggest that attaining and maintaining a healthy CRF could be successful in terms of one's AA. A more recent investigation also examined the relationship between changes in CRF and changes in mathematics and reading achievement between grades 6 and 8 [72]. Improvements between grades 6 and 8 in CRF were positively correlated with AA. The results from this study support and corroborate previous studies, suggesting that students who are more cardiorespiratory fit are more likely to perform better on AA tests. This highlights the long-term role of improving fitness and increasing AA. Thus, it seems that developmental changes in CRF are important to consider when examining changes in AA.

Further, in Taiwan, the association between change in fitness and subsequent change in AA from grade 7 to grade 9 was examined [73]. The regression analyses in this study confirmed that improvement in CRF was significantly associated with better AA. Interestingly, CRF exhibits stronger longitudinal associations with AA than other forms of fitness or body mass index for students. More recently, in Portugal, Sardinha et al. [74] examined the prospective associations between CRF and AA in students from grade 5 to grade 7. Results corroborated those observed previously, indicating that being persistently fit, compared with those classified as persistently unfit, increased the odds of having high levels of AA at follow-up. Students, who were unfit at baseline but improved their CRF and became fit, also had higher odds of achieving better marks than those persistently unfit. These longitudinal studies demonstrate that improvements in CRF are prospectively associated with better AA.

Summary: Numerous cross-sectional studies demonstrate that CRF is consistently associated with AA. Results from these studies are confirmed by recent longitudinal studies, indicating that low levels of CRF can jeopardized students' academic future. An investment in PA promotion and PE is important because it might play a role in the positive effect of PA, CRF and consequently cognition and AA.

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4. Potential mechanisms for the association between PA, CRF and AA

The association between PA, CRF and AA is not yet clearly understood. However, there are several potential mechanisms that may explain the association [75]. Animal and human research have been helpful in understanding the neurobiological mechanisms by which PA and CRF affect brain structure and function [76], cognition, [3, 4] and consequently AA [4]. Although understanding molecular and cellular changes in brain is currently limited in humans, larger scale neuronal changes can be assessed using neuroimaging tools. Advances in neuroimaging techniques have enabled the field of neuroscience to bridge the gap between animal and human studies. Changes in brain structure and function as a result of PA and CRF can now be addressed through an understanding of changes in the volume and thickness of neuronal tissue, via alterations in functional changes such as blood flow across brain regions, and through the understanding of how neural networks influence one another [76]. Furthermore, with a cross-talk mechanistic approach between organs, exercise may induce systemic factors released from peripheral organs such as muscle (myokines), liver (hepatokines) and adipose tissue (adipokines) that may contribute to neurotrophin and neurogenesis, as well as cognition and memory function [77]. Even though some uncertainties about the exact mechanisms remain, this is an evolving and promising field of research that further emphasizes the systemic and integrated effects of exercise on mechanisms that link biology to selected behaviors.

In school-aged children, a growing body of literature suggests differential brain structure related to CRF [75]. Specifically, an association has been shown among CRF, greater hippocampal volume, cognition and memory [78]. Such findings are interesting because the hippocampus is intricately involved in learning and memory, aspects of cognition important to AA, and these data suggest that CRF is beneficial to this subcortical region of the brain as well as the cognitive processes supported by it. Chaddock et al. [79] further observed differences in the basal ganglia, a subcortical structure involved in the interplay of cognition and willed action, between children with lower and higher CRF. Children with higher CRF exhibited greater volume in the dorsal striatum when compared to lower fit children. Such findings indicate that higher CRF is associated with better control of attention, memory and cognition. Children with better CRF exhibited increased inhibitory control and response resolution, and further higher basal ganglia volume was related to better task performance. These findings point to the dorsal striatum's involvement in higher order cognition and that CRF might influence cognitive control during children development.

Functional neuroimaging data have indicated that higher CRF is associated with increased cerebral blood flow in the microvasculature of the hippocampus in children, independent of sex, age and hippocampal volume [80]. Increased hippocampal blood flow is also linked to higher task performance on a spatial memory task. Thus, CRF might influence how the brain regulates its metabolic demands via blood flow to a particular region important for learning and memory.

To characterize PA-related differences in brain function, Davis et al. [81] used functional magnetic resonance imaging (fMRI) to investigate changes in the blood oxygen level dependent (BOLD) signal following PA intervention. Twenty sedentary, overweight children were randomized into an after-school PA intervention or a non-PA control group that lasted 14 weeks. Following the PA intervention, increased bilateral activation of the prefrontal cortex and decreased bilateral activation of the posterior parietal cortex was observed in the PA group relative to the non-PA control group. These differences in brain were elicited during tasks that tap inhibition, one aspect of executive control, indicating that the PA intervention affect brains function. A study, using fMRI, observed increased activation in prefrontal and parietal brain regions during early task blocks, and decreased activation during later task blocks in children with higher CRF relative to children with lower CRF [82]. As higher CRF children outperformed lower CRF children on aspects of the task requiring the greatest amount of executive control, higher CRF children appear more capable of adapting neural activity to meet the demands imposed by tasks that tapped higher order cognitive processes such as inhibition and goal maintenance. These two presented studies [81, 82] suggest that higher CRF children are more efficient in the allocation of resources in support of cognitive control operations.

Additional evidence may be derived from other investigations that have examined the neuroelectric system to investigate which cognitive processes occurring between stimulus engagement and response execution are influenced by CRF. Studies that examined the P3 component, a stimulus-elicited neuroelectric component involved in the allocation of attentional resources, have shown that higher CRF children have larger amplitude and shorter latency P3 response relative to their lower cardiorespiratory fit peers [21, 83]. Such findings indicate that higher CRF children allocate greater attentional resources and have faster cognitive processing speed relative lower cardiorespiratory fit children [21, 83]. Additional research also suggests that higher CRF children are related to greater flexibility in the allocation of attentional resources [81, 82].

At the biochemical level, investigations have shown that PA augments the synthesis of brain-derived neurotrophic factor (BDNF), which enhances brain plasticity by changing the structure of the neuron and strengthening its signaling capability [84]. An increase in BDNF is associated with increases in the volume of the hippocampus as well as improved memory performance [85]. Induced by PA (among other factors), BDNF activation is also related with increased long-term potentiation and neurogenesis [84]. Long-term potentiation is shown to improve learning and memory by strengthening the communication between specific neurons [86]. Based on animal studies, the increase in neurogenesis is hypothesized to increase learning [76, 84].

Figure 1 shows a simplify model of potential mechanisms for the relationship between PA, CRF and AA. PA may influence CRF. CRF, in turn, along with PA, are related with changes in brain structure, brain function and cognition. These changes may affect AA.

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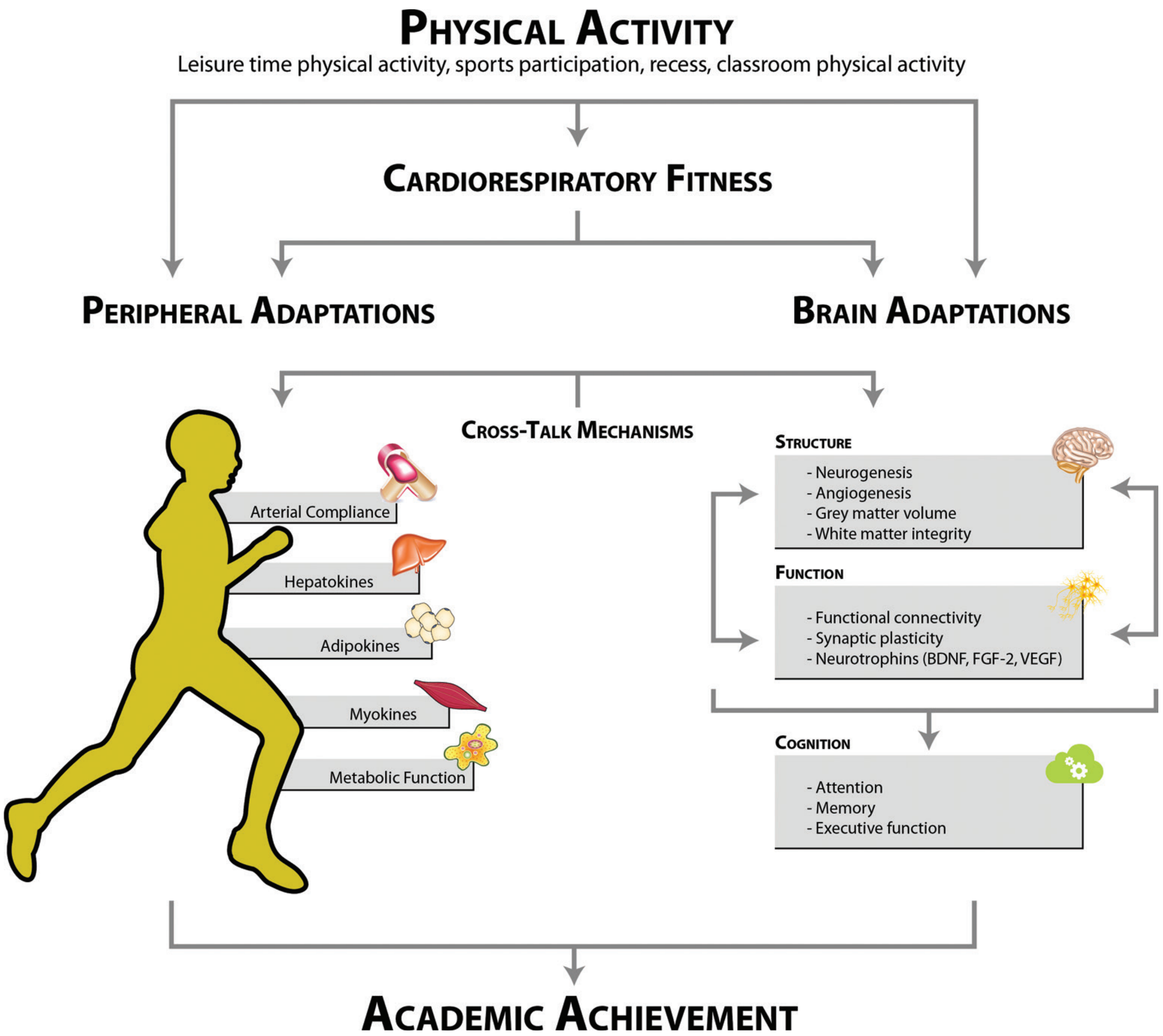

Figure 1. Simplified model of the relationship between physical activity, cardiorespiratory fitness and academic achievement. BDNF, brain-derived neurotrophic factor; FGF-2, fibroblast growth factor 2; VEGF, vascular endothelial growth factor.

Besides these physiological and psychological effects described above, PA practice and CRF improve students' behavior in the learning context, consequently increasing the odds of better concentration and achievement [56], which is directly related to AA.

Summary: The mechanisms underlying the relationship between PA, CRF and AA are not yet clearly understood. There is evidence that PA and CRF can affect brain structure and function using a variety of neuroimaging tools. At a biochemical level, CRF enhances the synthesis of brain-derived neurotrophic factor (among other molecular and cellular processes). Increasing BDNF is associated with increases in the volume of the hippocampus and improved memory.

5. Conclusion

This chapter presents evidence suggesting an association between PA, CRF and AA. Promoting PA and improvements in CRF are important for improving children and adolescents' health, and consequently, AA. Because students spend much of their daily lives in school, school-based PA may result in benefits to AA.

Attention to these findings is important because they have implications for students' education, predominantly in societies where economic development is important. With an increasing emphasis on formal academic disciplines, decision-makers are under pressure to achieve academic standards. Considering the relationship between PA, but mainly CRF, with AA, lower levels of CRF might jeopardize students' academic future. Therefore, changes in public policy are needed to systematically provide incentive and direction for increasing PA and enhanced CRF levels in school-aged children. Accordingly, it is justifiable for schools to increase time and resources to promote healthy and active lifestyles.

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