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A Review on the Dose Response Effect of Regular Physical Activity on Cognitive Function Among Children and Adolescents

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A Review on the Dose Response Effect of Regular Physical Activity on Cognitive Function Among Children and Adolescents

Abstract

Purpose: Positive effects of physical activity on cognitive function among children and adolescents have been observed in previous studies. However, little is known about whether there is a dose-response effect of physical activity on cognitive functioning. Especially, the curvilinear relationship between regular physical activity and cognitive functioning remained unexplored. The purpose of this paper was to review the literature on the dose response effect of physical activity on cognitive function among children and adolescents. Methods: A literature search on key words, title, and abstract with the phrases "physical activity and executive function", "physical activity and cognition", and "physical activity and cognitive function" was conducted by the authors on five databases: (a) Academic Search Complete; (b) ERIC; (c) Medline; (d) Pubmed; and (e) SportDiscus. Articles that met the inclusive and exclusive criteria were included in this review. Data including eight variables were extracted by the first author and validated by the second author independently. Results: Only four studies examined the dose-response effects of regular physical activities on cognitive functions. Little evidence is available to support the dose response effect. There is no evidence to support a curvilinear relationship between physical activity and cognitive function. Discussion and Conclusion: Research on the dose response effect of physical activity on cognitive function is still in its infancy. More research is warranted to further advance this line of research. Especially, future research should focus on what constitutes the minimal physical activity for cognitive benefits and what constitutes the optimal PA required to achieve maximal cognitive benefits. Findings from this line of research are critical to guiding future interventions and policies on increasing physical activity and cognitive function among children and adolescents in the United States.

A Review on the Dose Response Effect of Regular Physical Activity on Cognitive function among Children and Adolescents

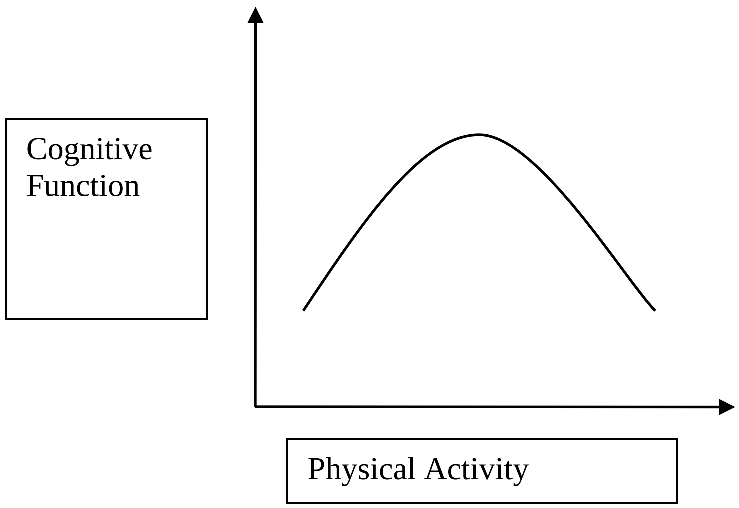
Introduction

By participating in regular physical activity (PA), children and adolescents can gain not only physical and mental health benefits, but also cognitive benefits. Emerging evidence from correlational studies shows that increased physical activity levels among children and adolescents are positively associated with improved cognitive functions (Mala et al., 2020; Sibley & Etnier, 2003). Experimental studies also show that increased physical activity levels among children and adolescents lead to improved cognitive functions (Donnelly et al., 2016; Spyridoula et al., 2019).

The previous studies mostly focused on the effect of regular physical activity on cognitive functioning among children and adolescents (Donnelly et al., 2016; Spyridoula et al., 2019). However, little is known about whether there is a dose-response effect of physical activity on cognitive functioning. Especially, the curvilinear relationship between regular physical activity and cognitive functioning remained unexplored. This line of inquiry can help us understand what constitutes the minimal physical activity for cognitive benefits and what constitutes the optimal PA required to achieve maximal cognitive benefits. A certain amount of physical activity can enhance cognitive functions among children and adolescents. However, too much may work against them (Van Der Mars, 2006), especially when physical fatigue occurs. It is possible that there is an inverted U-shaped relation between physical activity and cognitive functions, as reflected in Figure 1. That means, to achieve maximal cognitive functions, children and adolescents must maintain an optimal balanced amount of time and intensity spending on physical activity levels.

Researchers have begun to investigate if there is a dose-response relationship between regular physical activity and cognitive functioning (Davis et al., 2007, 2011). The purpose of this study, therefore, is to review the current research to identify evidence to support the dose response effect of physical activity on cognitive functions among children and adolescents and recommend future directions to advance this line of research inquiry. Cognitive functioning is a broad term that covers many varied and complex brain activities such as attention, perceptions, memory, awareness, processing speed, and executive functions. Executive function is a higher order cognitive ability which has been associated with frontal lobe activity.

Figure 1. An Inverted U-Shaped Function between Physical Activity and Cognitive Function



It functions by managing more basic cognitive functions (Alvarez & Emory, 2006; Etnier & Chang, 2009) and regulating emotions and attention (Blair & Diamond, 2008; Salthouse, 2007), which are necessary for purposeful, goal-directed behaviors. There is evidence suggesting that the effects of "chronic" (long term) physical activity are most evident in frontal lobe structure and function.[15] Even though recent research has shifted in focus from speed-of-processing tasks to executive function tasks, this review will focus on cognitive functioning due to limited research. This review is significant since the findings from this line of research are key to the design of evidence-based physical activity interventions that improve physical and mental health and cognitive functions among children and adolescents. They can also inform health and physical education and physical activity policy research with respect to the necessary amount of physical activity in which children and adolescents should be engaged for maximal cognitive benefits.

Methods

Literature Search

A literature search on key words, title, and abstract with the phrases "physical activity and executive function", "physical activity and cognition", and "physical activity and cognitive function" was conducted by the authors on five databases: (a) Academic Search Complete; (b) ERIC; (c) Medline; (d) Pubmed; and (e) SportDiscus.

Inclusive and Exclusive Criteria

The inclusive criteria are: (a) A focus on the dose-response or curvilinear relationship between regular physical activity and cognitive function; (b) Peer reviewed and empirical data-based journal articles; (c) Children and adolescents (0-18 years old) as study participants; and (d) written in English. Research articles, which examined the relationship between acute physical activity and cognitive function, had adults as participants, and were published in non-English journals, were excluded due to the focus of this review.

Literature Search Procedure and Study Selection

Through a zoom meeting, both authors worked together to complete the literature search and select the studies using the inclusive and exclusive criteria. The first author used key words to conduct the literature search using the five databases while the second author verified the search. The initial search from the five databases resulted in 75 articles from Academic Complete Search, Eric, Medline, and SportsDiscus (12 for physical activity and executive function, 13 for physical activity and cognitive function, and 20 for physical activity and cognition) and 1815 articles from PubMed (494 for physical activity and executive function, 482 for physical activity and cognitive function, and 839 for physical activity and cognition). Both authors simultaneously and carefully read the titles and abstracts and identified studies that met the inclusion and exclusion criteria. The full texts of the eligible studies based on the screened studies were read by both authors to determine their final inclusion. As a result, four studies were identified for this review.

Data Extraction Process and Data Synthesis

The following data were extracted by the first author and validated by the second author independently: (a) first authors' name, publication year; (b) sample size, participants' age, and country; (c) study design; (d) group assignments with details about intensity, frequency, and duration of intervention; (e) intervention length; (f) types of exercises; (g) cognitive measurements; and (h) main results. We only reported the main results focusing on the dose-response/curvilinear relationship between physical activity and cognitive functions.

Results

All the included articles examined the dose-response effects of regular physical activities on cognitive functions. Table 1 presents an overview of the included studies. Two studies were conducted in the United States. One study was conducted in Japan and another study was conducted in German. Two studies were randomized controlled trial, one was cross-sectional, and another one was quasi-experimental study with no randomization. The duration of physical activity interventions ranged from 7 days to 12 months. The type of intervention consisted of aerobic exercises in two studies, tennis in one study, and daily physical activities in another study. Two studies had specific doses of physical activity interventions (20 minutes versus 40 minutes) and the other two studies only classified doses as low and High. Two studies had a control group with no exercise and the other two studies did not have a control group. Cognitive measures included computerized cognitive tests and functional near-infrared spectroscopy. With regards to the dose-response relationship findings, Ishihara and Mizuno (2018) reported that participants in the high-dose group demonstrated greater improvements in working memory than those in the low dose group. Davis et al. (2011) reported that participants in the low- or high-dose of the exercise program had higher planning scores than those in the control group There were no significant differences in the changes of cognitive measures among participants from the low- and high-dose conditions. No quadratic trends were found. Mucke et al. (2018) found no significant differences in cognitive measures among children between lower and higher MVPA (moderate-to-vigorous physical activity) groups. Davis et al. (2007) reported that participants in the control group had a significantly lower posttest score in planning than those in the high-dose

Table 1. Overview of Included Studies

Authors (year)	Study Design	Sample	Groups (n)	Modality/Intensity	Intervention Length	Cognitive Measurements	Results
Davis, C. L. et al. (2011)	RCT	Sedentary overweight 7-11 years old from USA	Low: 20 min/day (55) High-dose: 40 min/day (56) CC: no exercise (60)	Aerobic excises: Running games, jump rope and modified basketball and soccer Intensity: an average >150 beats per minute	13 +/- 1.6 weeks	Cognitive Assessment System. Four interrelated cognitive processes: Planning, attention, Simultaneous, and Successive. Only the planning scale measures executive function. The remaining scales measure other aspects of cognitive performances.	Participants in the low- or high-dose of the exercise program had higher planning scores than those in the control group. No significant effects were found on the Attention, Simultaneous, or Successive scales. There were no significant differences in the changes of cognitive measures among participants from the low- and high-dose conditions. No quadratic trends were found.
Ishihara, T. & Mizuno, M. (2018)	Experimental study with pre and post tests. No randomization	32 6-11 year-old children from Japan	Low dose: Maintain current frequency (once a week) of tennis play (13) High dose: Increased frequency of tennis play to four times per week (13).	Tennis	12 months	Inhibitory control was assessed by using a modified Stroop Test. Working memory was assessed by using the 2-back Task. Cognitive flexibility was assessed by using a Local-global Task.	There was no main effect of group in reaction time and accuracy at baseline on the executive function task. An ANCOVA on 2-back Task reaction time at post-intervention showed a main effect of group, showing that participants in the high-dose group had shorter Reaction Times than those in the low-dose group. No main effect of group was detected in other task performance at post-intervention. Participants in the high-dose group demonstrated greater improvements in working

							memory than those in the low dose group.
Mucke, M. et al. (2018)	Non experimental study	55 10-11 year-old high school students from German	Lower MVPA (<124.1 min of MVPA per day) (20) Higher MVPA (>124.1 min of MVPA per day) (30)	Daily physical activities	7 consecutive days	verbal fluency tests (VFTs) and mental arithmetic (MA) for the assessment of cognitive flexibility and working memory capacity. During the tasks, changes of oxygenated haemoglobin were measured with functional near-infrared spectroscopy.	There were no significant differences in VFT and MA performance between children with lower and higher MVPA. There were no significant differences in HbO2 concentration changes in response to the cognitive tasks between children with lower and higher MVPA.
Davis C. L. et al. (2007)	RCT	94 sedentary overweight children 7-11 years old	Low dose (20 minutes/day exercise) (33) High dose (40 minutes/day exercise) (32) Control condition (29)	Running games, jump rope, and modified basketball and soccer: Average heart rate>150 bpm	5 days/week for 15 weeks	Cognitive Assessment System. Four interrelated cognitive processes: Planning, attention, Simultaneous, and Successive. Only the planning scale measures executive function. The remaining scales measure other aspects of cognitive performances.	There was a statistically significant effect for group assignment on the CAS Planning posttest score. Participants in the control group had a significantly lower posttest score than those in the high-dose exercise group. There was no statistically different for children in the low-dose group as compared to the high-dose group. There was not a dose-response relation.

exercise group. There was not significant difference in planning for children in the low-dose group as compared to the high-dose group. There was not a dose-response relation.

Discussion and Conclusion

Research on the dose response effect of physical activity on cognitive function is still in its infancy. Only four studies have been conducted on this line of research, and little evidence is available to support the dose response effect. Only one study found the dose-response effect of physical activity on cognitive function (Ishihara & Mizuno, 2018). The other three studies did not find any significant dose-response effect of physical activity on cognitive function (Davis et al., 2007, 2011; Mucke et al., 2018). The disparities in the findings can be contributed to various factors, including research design, cognitive measurements, intervention length, characteristics of children and adolescents, task specificity, and the ways how doses were defined. For examples, doses of physical activity were defined differently in the previous studies. Two studies used high versus low, while the other two studies used specific amounts of time as doses (20 minutes versus 40 minutes). There is no evidence to support a curvilinear relationship between physical activity and cognitive function. One possible reason is that the doses chosen in the previous studies may not be enough to elicit a curvilinear effect of physical activity on cognitive function. More research is warranted to further advance this line of research. Especially, future research should focus on what constitutes the minimal physical activity for cognitive benefits and what constitutes the optimal PA required to achieve maximal cognitive benefits. Findings from this line of research are critical to guiding future interventions and policies on increasing physical activity and cognitive function among children and adolescents in the United States.

Executive function is a higher order cognitive ability and functions by managing more basic cognitive functions (Alvarez & Emory, 2006; Etnier & Chang, 2009). Recent research has shifted in focus from speed-of-processing tasks to executive function tasks (Etnier & Chang, 2009). Future research shall focus on the effect of physical activity on executive function rather than basic cognitive functions. In addition, given the breadth of the executive function construct, the choice of executive function measures can have a significant effect on the outcomes of this line of research[15]. The previous studies only assessed some aspects of executive function (Davis et al., 2007, 2011; Ishihara & Mizuno, 2018; Mucke et al., 2018) and may not represent the breadth of this construct. Future research shall examine other aspects of executive function, use multiple measures to assess cognitive function, and use measures that are more sensitive to the effects of physical activity (Etnier & Chang, 2009).

Task specificity such as cognitive engagements or demands may affect the effect of physical activity and cognitive function (Meijer et al., 2021; Pesce, 2012; Tomporowski & Pesce, 2019). Cognitive engagements or demands may improve the brain connectivity through axonal arborization or increased cell density between brain structures, which are engaged in cognitive functioning (Best, 2010; Meijer et al., 2021; Tomporowski et al., 2015). Some studies found that sports or exercises with high cognitive demands produced stronger effects on cognitive function (Koutsandreou et al., 2016; Schmidt et al., 2015). However, there is also evidence showing that high cognitive demands failed to produce a stronger effect on cognitive function (Meijer et al., 2021). It is suggested that future research should further investigate the effect of task specificity.

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