



## Review article

Translating the neuroscience of physical activity to education<sup>☆</sup>Brian M. Gearin<sup>a,\*</sup>, Hank Fien<sup>b</sup><sup>a</sup> Department of Education, Methodology, Policy, and Leadership, University of Oregon, United States<sup>b</sup> Department of Special Education and Clinical Sciences, University of Oregon, United States

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## ABSTRACT

Over the past two decades, a body of research has emerged that suggests that physical activity has beneficial effects on the brain's structure and function. During the same period, concern has mounted over high rates of childhood obesity. Considering that schools have been called on to both improve academic achievement and childhood obesity rates, it is surprising that schools have not exploited research on physical activity's cognitive effects. However, a closer examination of the literature reveals major gaps in knowledge that hinder neuroscientific findings from being readily translated into practice. Here, we provide an overview of research on physical activity's cognitive effects. We then identify the most pressing gaps in knowledge and make suggestions for how they can be addressed.

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## 1. Introduction

There is a growing concern that children are not meeting the recommended amount of daily physical activity (PA)<sup>1</sup> despite warnings that childhood obesity may cause the current generation to have lower life expectancies than their parents [1], and despite

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mounting evidence that PA promotes healthy brain development [2]. National and international health organizations are citing schools as fundamental to any systematic effort to raise PA levels [3–8]. However, many school systems are spending less time and money on dedicated PA programs due to academic accountability demands and budgetary constraints [4,9–11]. There is also a large discrepancy between international physical education policy and its actual implementation in schools [10]. The large number of governmental reports and strategic policy documents aimed at bolstering PA's place in school give a sense of the scope and persistence of these problems [4,8,10,12–14]. However, there is little evidence that these policy documents and PA recommendations are making their way into schools. A European Commission report found that physical education made up less than 10% of total taught time in the average European school from 2011 to 2012 [13]. In the United States, only 3.8% of elementary schools offered daily physical education in 2006, and only 13.7% offered it three days per week [4]. These latter figures are about half as high as they were in 2000 [4].

A body of neuroscientific research suggests that schools should be taking the opposite approach: by increasing student PA levels, schools may be able to improve student cognition and academic achievement, thereby satisfying their accountability demands. At first glance, it is surprising that this neuroscientific research has not been translated into practice given the intense governmental interest in increasing school-based PA. However, a critical analysis of the literature reveals major gaps in knowledge that must be closed if successful translation is going to occur. According to Varma, McCandliss, and Schwarz, two types of concerns must be addressed in order to successfully translate neuroscience into education: scientific concerns and pragmatic concerns [15]. Previous research has focused almost exclusively on scientific concerns (i.e., methods, data, and theory). Researchers have sought to demonstrate that PA has the potential to enhance cognition in ways that may benefit schools, and they have largely succeeded. Pragmatic concerns, like how this might be done, have not been adequately addressed. In order to begin reversing this trend, we provide a brief overview of research on PA's cognitive effects. We then identify the most pressing pragmatic concerns, and recommend potential solutions.

## 2. PA and cognition

PA is any bodily movement produced by skeletal muscle that results in energy expenditure [16]. It is a broader concept than exercise, which is a planned and repetitive activity performed to enhance fitness. Although it has been recognized since Antiquity that a healthy body leads to a healthy mind, it was not until the late 1990s that a coherent program of psychological research on PA began to emerge. Meta-analyses played a particularly important role in facilitating this shift because they suggested that PA could improve educational test performance and student affect

(Tables 1 and 2). However, the mechanisms behind these meta-analytic findings remained unidentified until the early 2000s. At this point, converging evidence from adult and rodent studies were synthesized, and formal logic models were proposed (e.g., Fig. 1).

As research progressed throughout the 2000s, studies began to focus on PA's relationship with children's brain structure and function. Cross-sectional studies demonstrated that physical fitness in children is associated with increased basal ganglia volume [17], hippocampal volume [18], white matter integrity [19], and decreased gray matter thickness in superior frontal cortex, superior temporal areas, and lateral occipital cortex [20]. Respectively, these areas of the brain are believed to be involved in action-selection and reward-learning [17]; the formation of new relational memories and the "relational binding" process involved in successful memory retrieval [18]; information processing, learning and cognitive control [21]; and arithmetic processing [20]. Studies also analyzed the relationship between physical fitness and children's brain function [22–29] and aerobic exercise and children's brain function [30–38]. These studies demonstrated associations between aerobic fitness and certain aspects of cognition (i.e., attention and inhibition), and aerobic exercise and certain aspects of cognition, with higher-fit or exercising children often demonstrating preferable performance on psychological tests, and producing different magnetic resonance images and event-related potential data from their lower-fit or sedentary peers.

In sum, researchers have put to rest the question of *whether* PA has important cognitive benefits. Greater consideration must now be given to pragmatic concerns, such as *how* PA enhances cognitive function, and whether this enhanced functioning has practical implications for schools [39]. These pragmatic concerns are the subject of the remainder of this review. We have organized these pragmatic concerns into two types: acknowledged problems and

**Table 1**  
Meta-analyses on the effect of physical activity on children's cognition.

| Study                   | Type                         | k  | Cognitive domain           | ES      | Comments                                                                                                                                                                                                                                                                                     |
|-------------------------|------------------------------|----|----------------------------|---------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Etnier et al. [105]     | Acute and chronic aggregated | 39 | Cognition                  | 0.41*   | Effect sizes for different study designs combined. Effects reported for other moderating variables, but not for the child age group.                                                                                                                                                         |
|                         |                              | 8  | Ages 6–13                  | 0.36*   |                                                                                                                                                                                                                                                                                              |
|                         |                              | 8  | Ages 14–17                 | 0.77*   |                                                                                                                                                                                                                                                                                              |
| Sibley and Etnier [106] | Acute and chronic aggregated | 5  | Perception                 | 0.49*   | Quality and power of reviewed studies generally low. No evidence of publication bias. Effect sizes for specific study designs available.                                                                                                                                                     |
|                         |                              | 15 | Other                      | 0.40*   |                                                                                                                                                                                                                                                                                              |
|                         |                              | 7  | Developmental level        | 0.39*   |                                                                                                                                                                                                                                                                                              |
|                         |                              | 21 | Intelligence quotient      | 0.34*   |                                                                                                                                                                                                                                                                                              |
|                         |                              | 33 | Achievement                | 0.30*   |                                                                                                                                                                                                                                                                                              |
|                         |                              | 7  | Math                       | 0.20*   |                                                                                                                                                                                                                                                                                              |
|                         |                              | 12 | Verbal                     | 0.17*   |                                                                                                                                                                                                                                                                                              |
|                         |                              | 7  | Memory                     | 0.03    |                                                                                                                                                                                                                                                                                              |
|                         |                              | 7  | Memory                     | 0.03    |                                                                                                                                                                                                                                                                                              |
| Fedewa and Ahn [48]     | Acute and chronic aggregated | 13 | Total achievement          | 0.27**  | Included RCT's and cross-sectional studies. No evidence of publication bias. Effect sizes for specific study designs available.                                                                                                                                                              |
|                         |                              | 13 | Math achievement           | 0.44**  |                                                                                                                                                                                                                                                                                              |
|                         |                              | 19 | Intelligence quotient      | 0.39**  |                                                                                                                                                                                                                                                                                              |
|                         |                              | 14 | Reading achievement        | 0.36**  |                                                                                                                                                                                                                                                                                              |
|                         |                              | 6  | English language/art       | 0.22**  |                                                                                                                                                                                                                                                                                              |
|                         |                              | 10 | Grade point average        | 0.24**  |                                                                                                                                                                                                                                                                                              |
|                         |                              | 15 | Other                      | 0.25**  |                                                                                                                                                                                                                                                                                              |
| Chang et al. [47]       | Acute                        | 1  | Science                    | 0.15    | Effect sizes for different study designs available. Not enough studies on children included to draw conclusions for this population. Effect size reported in Cohen's <i>d</i> .                                                                                                              |
|                         |                              | 9  | Cognition                  | 0.05    |                                                                                                                                                                                                                                                                                              |
|                         |                              | 9  | Ages 6–13                  | 0.17*   |                                                                                                                                                                                                                                                                                              |
| Verburgh et al. [67]    | Acute                        | 19 | Overall executive function | 0.52*** | Acute and chronic studies analyzed used different designs. No correlation between study quality and effect size found. Not enough studies to draw conclusions about the effects of chronic exercise on children. No evidence of publication bias. Effect size reported in Cohen's <i>d</i> . |
|                         | Chronic                      | 5  |                            | 0.14    |                                                                                                                                                                                                                                                                                              |

*Note:* Acute exercise is a single bout of exercise. Chronic exercise refers to multiple bouts of exercise. When one effect size is reported for the aggregation of acute and chronic studies, it is not possible to make inferences about cumulative effects. Effect sizes reported in Hedge's *g* unless noted. RCT=randomized control trial.

\*  $p < 0.05$ .

\*\*  $p < 0.01$ .

\*\*\*  $p < 0.001$ .

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