



Health-related physical fitness, academic achievement, and neuroelectric measures in children and adolescents

Chien-Heng Chu, Feng-Tzu Chen, Matthew B. Pontifex, Yanlin Sun & Yu-Kai Chang

To cite this article: Chien-Heng Chu, Feng-Tzu Chen, Matthew B. Pontifex, Yanlin Sun & Yu-Kai Chang (2016): Health-related physical fitness, academic achievement, and neuroelectric measures in children and adolescents, International Journal of Sport and Exercise Psychology, DOI: [10.1080/1612197X.2016.1223420](https://doi.org/10.1080/1612197X.2016.1223420)

To link to this article: <http://dx.doi.org/10.1080/1612197X.2016.1223420>



Published online: 01 Sep 2016.



Submit your article to this journal [↗](#)



Article views: 61



View related articles [↗](#)



View Crossmark data [↗](#)



Citing articles: 2 View citing articles [↗](#)

Health-related physical fitness, academic achievement, and neuroelectric measures in children and adolescents

Chien-Heng Chu^a, Feng-Tzu Chen^a, Matthew B. Pontifex^b, Yanlin Sun^c and Yu-Kai Chang^{a*}

^a*Graduate Institute of Athletics and Coaching Science, National Taiwan Sport University, Taoyuan, Taiwan;* ^b*Department of Kinesiology, Michigan State University, MI, USA;* ^c*Keylab of Sport Psychology, Tianjin University of Sport, Tianjin, People's Republic of China*

(Received 20 December 2015; accepted 10 May 2016)

The association between health-related physical fitness and academic achievement has captured the interest of educators and researchers. The purpose of this review is to examine the relationships between health-related physical fitness and academic achievement among children and adolescents, as well as to assess the association between health-related physical fitness and event-related potentials indicative of neurocognitive processes. Cardiorespiratory fitness was positively associated with performance in the majority of academic subjects as well as with core neurocognitive processes that are foundational to scholastic performance. The association among muscular strength, muscular endurance, and flexibility with academic achievement was less consistent. As expected, body mass index (a surrogate measure of body composition) was negatively associated with academic scores in the majority of academic subjects as well as being predictive of impaired attentional resource allocation and inefficient action monitoring. These findings suggest differential relationships between components of health-related fitness and academic achievement as well as underlying neurocognitive processes. Future research regarding the effect of multiple aspects of health-related physical fitness on youth's academic achievement and adopting a neuroelectric perspective is warranted.

Keywords: cardiorespiratory fitness; muscular strength; muscular endurance; body mass index; FITNESSGRAM; cognition; executive function

Accumulating evidence indicates that engagement in physically active behaviours is associated with a wide range of health benefits including reduction of cholesterol, high blood pressure, and metabolic risk factors (Janssen & Leblanc, 2010). Beyond enhancements in physical function, benefits have also been observed for aspects of mental health, including reductions in depression and anxiety (Biddle & Asare, 2011) and enhanced cognitive function (Erickson, Hillman, & Kramer, 2015). Within pediatric populations, meta-analytic reviews suggest a small-to-moderate positive association between physical activity and cognition (Sibley & Etnier, 2003), such that higher levels of physical activity are associated with superior cognitive performance that are believed to underlie scholastic achievement (van Dinteren, Arns, Jongsma, & Kessels, 2014).

The premise that increasing physical activity might contribute to enhanced academic achievement and learning abilities has garnered interest among educators and exercise researchers (Tomprowski, Lambourne, & Okumura, 2011). Notably, however, evidence regarding the

*Corresponding author. Email: yukaichangnew@gmail.com

association between physical activity and the broader construct of academic achievement has been equivocal, with some research indicating a weak negative association (Esteban-Cornejo et al., 2014), while other results are not strong such that they can only report no harmful effect of physical activity on academic achievement (Coe, Pivarnik, Womack, Reeves, & Malina, 2006; Dwyer, Sallis, Blizzard, Lazarus, & Dean, 2001). These inconsistent findings might be due to the difficulty of precisely assessing amount of physical activity via self-report questionnaires in children (Rachele, McPhail, Washington, & Cuddihy, 2012). Therefore, physical fitness has been suggested to be a more informative physical exercise index for academic achievement (Blom, Alvarez, Zhang, & Kolbo, 2011; Hansen, Herrmann, Lambourne, Lee, & Donnelly, 2014).

Physical fitness refers to a set of health- and skill-related attributes a person has in regard to their ability to perform physical activity behaviours. Our goal is to examine five components of health-related physical fitness including cardiorespiratory fitness, muscular strength, muscular endurance, flexibility, and body composition (Ortega, Ruiz, Castillo, & Sjostrom, 2008) as predictors of academic achievement and cognitive function. These particular components were selected because they have been identified as important health markers in childhood and adolescence and they relate to risk factors associated with chronic and degenerative diseases (American College of Sports Medicine, 2010; Castillo-Garzon, Ruiz, Ortega, & Gutierrez-Sainz, 2007; Ruiz et al., 2009). In a previous review, Keeley and Fox (2009) reported a positive association between physical fitness and academic achievement; however, only four studies in the review (Eveland-Sayers, Farley, Fuller, Morgan, and Caputo 2009; Castelli, Hillman, Buck, and Erwin 2007; Grissom 2005; Dwyer et al. 2001) assessed health-related physical fitness. Since then, additional studies have been conducted to explore this relationship and our goal is to provide a review of this literature with a particular focus on delineating the specific relationships of each component of health-related physical fitness with academic achievement.

Event-related brain potentials (ERPs) are also of relevance in considering the potential relationship between health-related physical fitness and cognitive performance. ERPs provide a means of examining distinct cognitive operations that might contribute to academic achievement (Hillman et al., 2012; Pontifex et al., 2011). ERPs refer to patterns of neuroelectric activation that occur in preparation for, or in response to, an event. One subset of ERP components is time locked to the onset of a stimulus, with the naming convention of these components corresponding to their respective direction and ordinal positioning (Hruby & Marsalek, 2003). Several ERP components have been linked to the neurocognitive processes that might be important to the academic achievement. For instance, an endogenous component P300 is believed to reflect suppression of extraneous neural operations in order to facilitate attentional processing (Polich, 2007). Other components such as the N400 and P600 are elicited during sentence or sequential processing and have been found to provide an index of semantic and syntactic processing, respectively (Weber-Fox, Davis, & Cuadrado, 2003). Furthermore, the error-related negativity is time locked to the onset of an incorrect response and has been associated with the activation of action-monitoring processes in order to initiate top-down compensatory processes (Nieuwenhuis, Ridderinkhof, Blom, Band, & Kok, 2001).

A considerable number of studies have demonstrated the association between physical fitness and ERP components. For example, children with higher cardiorespiratory fitness demonstrated larger P300 (also called P3) amplitude, suggesting that higher fitness children had superior capacity to allocate attentional resource (Hillman, Castelli, & Buck, 2005; Pontifex et al., 2011). Similarly, these ERP components have been linked to academic performance (Hirsh & Inzlicht, 2010), grade level (Hillman et al., 2012), or semantic processing and vocabulary (Khalifian, Stites, & Laszlo, 2015). However, research associated with physical fitness and ERPs has focused almost exclusively on cardiorespiratory fitness. Few studies have explored the

relationships between health-related physical fitness and academic achievement from an ERP perspective. The purpose of this review is to investigate how health-related fitness attributes such as cardiorespiratory fitness, muscular strength, muscular endurance, flexibility, and body composition relate to academic achievement and to underlying neuroelectric activity.

Literature review

Search strategy and eligibility criteria

In order to identify potentially relevant articles, terms related to health-related physical fitness were searched within major computerised-database, including MEDLINE, PubMed, PsycINFO, SportDiscus, Educational Research in Completion (ERIC), ScienceDirect, and Cochrane Controlled Trials Register (CENTRAL). The specific search terms included *physical fitness, health-related fitness, fitness, cardiorespiratory fitness, cardiovascular, cardiorespiratory, PACER, Progressive Aerobic Cardiovascular Endurance Run, abdominal strength, abdominal endurance, muscular strength, muscular endurance, flexibility, upper body strength, upper body endurance, trunk extensor strength, body mass, body composition, FITNESSGRAM, and the President's Challenge Programme*. The use of the term academic achievement was restricted to direct objective indicators of academic achievement (i.e. grade point average (GPA) and scores on standardised tests). Specifically, the search terms included *mat*, reading, reasoning, spelling, grade point average/GPA, Scholastic Assessment Tests/SAT, achievement, educational, and educational status*. Criteria of eligible studies were (a) study employed cross-sectional design; (b) age range of participants was between 6 and 16 years; (c) studies were peer-reviewed; and (d) studies were published in English between January 2000 and January 2015.

Description of studies

The literature search yielded a total of 13 of studies (11 from the USA, 1 each from the Netherlands and Sweden) that met the criteria. These investigations utilised sample sizes ranging from 134 to 884,715 participants with ages ranging from 7 to 16 years. Eight of these studies utilised the USA FITNESSGRAM (see [Table 1](#)) and five utilised other physical fitness assessment methods (see [Table 2](#)).

The FITNESSGRAM includes six components, which represent three broad categories of health-related physical fitness: (a) cardiorespiratory fitness; (b) muscular strength, endurance, and flexibility; and (c) body composition. Cardiorespiratory fitness is assessed using the Progressive Aerobic Cardiovascular Endurance Run (PACER), a one-mile run/walk, or a one-mile walk. Muscular strength and endurance of FITNESSGRAM is further divided into abdominal strength and endurance (e.g. using the curl-up test), upper body strength and endurance (e.g. using push-ups), and trunk extensor strength (e.g. using the truck lift). Regarding flexibility, the back-saver sit-and-reach test and shoulder stretch test are two commonly used physical fitness tests that are part of the FITNESSGRAM. Finally, body composition is examined by measuring skinfolds or through calculating BMI (Welk & Meredith, 2008).

The physical fitness performance of a child, such as cardiorespiratory fitness and muscular strength, endurance and flexibility, is evaluated by criterion-referenced health standards, which is used to determine whether a child's performance meets the minimum health levels designated as the Healthy Fitness Zone (HFZ). If a child performs at or above the minimum criterion-referenced standard indicating sufficient fitness for good health for that fitness component, the child is classified as being in the HFZ; otherwise, his/her performance is labeled as "Needs Improvement (NI)" (Welk & Meredith, 2008).

Table 1. Studies examining the relationship between PF assessed by FITNESSGRAM and academic achievement.

Reference	Sample characteristics	Assessment of PF components, methods	Academic test, academic subjects	Main results
Blom et al. (2011) US	<i>N</i> = 2992 (Male = 52.4%) Grade: 3~8	TPF: six HFZs (ASE, BC, CRF, F, TESF and UBSE) ASE: CU BC: BMI (FG) CRF: PACER F: back-saver SR TESF: TL UBSE: PUSH	MCT2: language arts math	<i>Relationships between PF and AA:</i> TPF: (+): language arts (+): math <i>Adjusted odds ratios for high achievement:</i> language arts: Girls = 1.23 (boy = 1.0) math: Girls = 1.29 (boy = 1.0)
Castelli et al. (2007) US	<i>N</i> : 259 (Male = 51.0%) <i>M</i> _{age} : 9.5 ± 0.7 yrs Grade: 3 and 5	TPF: five HFZs (ASE, BC, CRF, F and UBSE): ASE: CU BC: BMI (FG) CRF: PACER F: back-saver SR UBSE: PUSH	ISAT: math reading TAS	<i>Relationships between PF and AA:</i> ASE: (+): math (+): reading (+): TAS BMI: (-): math (-): reading (-): TAS CRF: (+): math (+): reading (+): TAS UBSE: (+): math (+): reading (+): TAS F: (+): math (+): TAS TPF: (+): math (+): reading (+): TAS <i>Relationships between PF and AA (after including age, gender, BMI, fitness, and school characteristics):</i> BMI: (-): math (-): reading (-): TAS CRF: (+): math (+): reading (+): TAS TPF: (+): math (+): reading (+): TAS

(Continued)

Table 1. Continued.

Reference	Sample characteristics	Assessment of PF components, methods	Academic test, academic subjects	Main results
Cottrell et al. (2007) US	N: 968 (Male = 50.7%) M_{age} : 10.6 yrs Grade: 5	TPF: Five HFZs (ASE, CRF, F, TESF and UBSE) ASE: CU BC: BMI (CDC) CRF: PACER or O F: back-saver SR or SS TESF: TL UBSE: PUSH, MPULL, PULL or FAH	WESTEST: reading/ language arts math science social study	<i>Relationships between PF and AA (after controlling for financial needs):</i> BMI: (-): reading/ language arts (-): math (-): science <i>Relationships between PF and AA (after including cardiovascular risk factors, gender, financial need, BMI and fitness):</i> TPF: (+): reading/language arts (+): math (+): science (+): social study
Grissom (2005) US	N: 884,715. Grade: 5, 7 and 9	TPF: 6 HFZ (ASE, BC, CRF, F, TESF and UBSE) ASE: CU BC: BMI (FG) CRF: PACER or O F: back-saver SR or SS TESF: TL UBSE: PUSH, MPULL, PULL or FAH	SAT-9: math reading	<i>Relationships between PF and AA:</i> TPF: (+): reading (+): math
Hansen et al. (2014) US	N:687 (Male = 50.0%) M_{age} : 7.8 ± 0.6 yrs Grade: 2 and 3	CRF: PACER	WIAT-III: math reading spelling	<i>Relationships between PF and AA:</i> CRF: (+): math (Quadratic association; plateaued at 27.1 PACER laps) (+): spelling (Quadratic association; plateaued at 22.7 PACER laps)
Roberts et al. (2010) US	N: 1989 (Male = 50.9%) Grade: 5, 7 and 9	BC: BMI (CDC) CRF: O	CAT-6 and CST: language test math reading	<i>Relationships between PF and AA:</i> BMI: (-): language test (-): math (-): reading CRF: (+): language test (+): math (+): reading <i>Relationships between PF and AA (after including age, gender, SES, fitness and BMI):</i> CRF: (+): language art (+): math (+): reading

(Continued)

Table 1. Continued.

Reference	Sample characteristics	Assessment of PF components, methods	Academic test, academic subjects	Main results
Welk et al. (2010) US	N: 36,835 (Male = 50.2%) Grade: 3~12	BC: BMI (FG) CRF: PACER or O	TAKS	<i>Relationships between PF and AA (after controlling for gender, age, SES and school characteristics):</i> BMI: (-): % of students achieving age-specific TAKS standard CRF: (+): % of students achieving age-specific TAKS standard
Wittberg et al. (2009) US	N: 968 (Male = 50.7%) M_{age} : 10.6 yrs Grade: 5	ASE: CU BC: BMI (CDC) CRF: PACER or O F: BSSR and SS TESF: TL UBSE: PUSH, MPULL, PULL or FAH	WESTEST: math reading/ language arts science social study	<i>Relationships between PF and AA:</i> ASE: (+): math (+): reading/ language arts (+): science (+): social study CRF: (+): math (+): reading/ language arts (+): science (+): social study UBSE: (+): math F: (+): math (+): science <i>Relationships between PF and AA (after controlling for BMI, gender and SES):</i> CRF: (+): math (+): reading/language arts (+): science (+): social study

Notes: **AA**: academic achievement; **ASE**: abdominal strength and endurance; **BC**: body composition; **BMI**: body mass index; **CU**: curl-up test; **CAT-6**: California Achievement Test, Sixth Edition; **CDC**: Centers for Disease Control and Prevention; **CRF**: cardiorespiratory fitness; **CST**: California Standards Test; **F**: flexibility; **FAH**: flexed-arm hang test; **FG**: FITNESSGRAM; **HFZ**: healthy fitness zone; **ISAT**: Illinois Standards Achievement Test; **MPULL**: modified pull-up test; **MAge**: average age; **MCT2**: Mississippi Curriculum Test; **N**: number of participants; **O**: one-mile run/walk test; **TAS**: total academic scores; **PUSH**: push-up test; **PACER**: Progressive Aerobic Cardiovascular Endurance Run test; **PULL**: pull-up test; **SES**: socioeconomic status; **SS**: shoulder stretch test; **SR**: sit-and-reach test; **TAKS**: Texas Assessment of Knowledge and Skills; **TESF**: trunk extensor strength and flexibility; **TL**: trunk lift test; **TPF**: total PF score; **UBSE**: upper body strength and endurance; **WESTEST**: West Virginia Educational Standards Test; **WIAT-III**: Weschsler Individual Achievement Test-Third Edition; (+): significant positive association between the physical fitness component and academic achievement; (-): significant negative association between the physical fitness component and academic achievement.

Other than FITNESSGRAM, studies included additional measures of cardiorespiratory fitness such as a 20-m endurance shuttle run, a 10 × 5 shuttle run and maximal power output. Regarding flexibility, it was assessed by measures in the FITNESSGRAM and by the sit-and-reach test and the V-sit reach test. Finally, parallel to the FITNESSGRAM BMI standards, BMI standards were

also determined from growth charts published by the Centers for Disease Control and Prevention (CDC).

Health-related physical fitness and academic achievement: findings

Cardiorespiratory fitness. Among these studies, 13 examined the association between cardiovascular fitness and academic achievement (Blom et al., 2011; Castelli et al., 2007; Chomitz et al., 2009; Cottrell, Northrup, & Wittberg, 2007; Eveland-Sayers et al., 2009; de Greeff et al., 2014; Grissom, 2005; Hansen et al., 2014; Kwak et al., 2009; Martin & Chalmers, 2007; Roberts, Freed, & McCarthy, 2010; Welk et al., 2010; Wittberg, Northrup, & Cottrell, 2009). Positive associations between cardiorespiratory fitness and academic achievement were observed with the academic achievement indexed using total academic scores (Castelli et al., 2007; Kwak et al., 2009) and percentage of students achieving age-specific academic standards (Welk et al., 2010). Further, cardiorespiratory fitness has been consistently reported to exhibit a positive association with mathematics (Castelli et al., 2007; Eveland-Sayers et al., 2009; de Greeff et al., 2014; Hansen et al., 2014; Roberts et al., 2010; Wittberg et al., 2009). For instance, de Greeff et al. (2014) and Eveland-Sayers et al. (2009) examined the 20-m endurance shuttle run and one-mile run, respectively, and reported a positive relation of cardiorespiratory fitness to mathematics achievement scores.

Cardiorespiratory fitness also appears to be positively associated with other academic areas (Castelli et al., 2007; Hansen et al., 2014; Roberts et al., 2010; Wittberg et al., 2009). For example, Wittberg et al. (2009) observed a positive association between cardiorespiratory fitness and performance on academic achievement tests in the areas of science and social studies in a sample of 968 preadolescent children. A similar positive association between cardiorespiratory fitness and spelling has also been reported by Hansen et al. (2014) and de Greeff et al. (2014). Additionally, cardiorespiratory fitness has been positively correlated with language arts performance (Roberts et al., 2010; Wittberg et al., 2009). The association between cardiorespiratory fitness and reading performance is less consistent. Some studies reported positive associations between cardiorespiratory fitness and reading performance for both genders in some studies (Castelli et al., 2007; Roberts et al., 2010; Wittberg et al., 2009), and one study indicated the positive association only existed among girls (Eveland-Sayers et al., 2009). Furthermore, a recent investigation by de Greeff et al. (2014) failed to observe a relationship between cardiorespiratory fitness, assessed using an endurance shuttle run similar to the PACER fitness test and academic performance in reading.

Considering the findings from these studies, it seems that the associations of cardiorespiratory fitness to mathematics, spelling, science, and social studies are consistently observed in children and adolescents.

Muscular strength and endurance. Nine of 13 studies assessed muscular strength and endurance (Blom et al., 2011; Castelli et al., 2007; Chomitz et al., 2009; Cottrell et al., 2007; Eveland-Sayers et al., 2009; de Greeff et al., 2014; Grissom, 2005; Martin & Chalmers, 2007; Wittberg et al., 2009). However, in these studies, the strength and endurance measures were typically combined with other measures of fitness to create a composite measure of physical fitness. Only four studies have specifically examined the associations between muscular strength, muscular endurance, and academic achievement (Castelli et al., 2007; Eveland-Sayers et al., 2009; de Greeff et al., 2014; Wittberg et al., 2009).

Positive associations between abdominal strength and academic performance have been observed, with greater abdominal strength relating to enhanced performance in the academic areas of mathematics (Castelli et al., 2007; Eveland-Sayers et al., 2009; Wittberg et al., 2009), reading (Castelli et al., 2007; Grissom, 2005; Wittberg et al., 2009), language arts, science, and

social studies (Wittberg et al., 2009). In addition, upper body strength has been found to have a positive association with scholastic achievement in the areas of reading (Castelli et al., 2007; Grissom, 2005) and mathematics (Castelli et al., 2007; Wittberg et al., 2009). However, it is of note that, when the studies controlled for potential covariates such as age and socioeconomic status, the associations among abdominal strength, upper body strength, and academic achievement were weakened (Castelli et al., 2007; Wittberg et al., 2009). Finally, only one study specifically examined trunk extensor strength and flexibility and there was no significant relationship with any measure of academic achievement (Wittberg et al., 2009).

Relatively few studies have specifically examined the association between muscular fitness and scholastic achievement in youth. While the evidence is generally supportive of a positive association between abdominal and upper body muscular strength, flexibility, and mathematics, the relationship might be academic-subject and muscular-group dependent.

Flexibility. Eight of 13 studies assessed flexibility (Blom et al., 2011; Castelli et al., 2007; Chomitz et al., 2009; Cottrell et al., 2007; Eveland-Sayers et al., 2009; Grissom, 2005; Martin & Chalmers, 2007; Wittberg et al., 2009), but only two directly investigated the relation between muscular flexibility and scholastic performance and these studies failed to find any association (Castelli et al., 2007; Wittberg et al., 2009).

Body composition. Ten studies discussed the association between body composition and scholastic achievement. Among these studies, four studies used the FITNESSGRAM BMI standards (Blom et al., 2011; Castelli et al., 2007; Grissom, 2005; Welk et al., 2010), five studies employed the CDC-defined BMI standards (Chomitz et al., 2009; Cottrell et al., 2007; Eveland-Sayers et al., 2009; Roberts et al., 2010; Wittberg et al., 2009), and one study utilised the sum of the skinfolds measure as the body composition index (Kwak et al., 2009).

With the exception of the study by Kwak et al. (2009), studies investigating the relation between body composition and academic achievement have relied on BMI as a surrogate measure of body composition. Findings from these studies largely suggest a negative relation between BMI and multiple aspects of academic achievement (Castelli et al., 2007; Cottrell et al., 2007; Eveland-Sayers et al., 2009; Grissom, 2005; Roberts et al., 2010; Welk et al., 2010; Wittberg et al., 2009). For example, Castelli et al. (2007) observed a negative association between FITNESSGRAM-defined BMI and academic scores, reading scores, and mathematics scores, even after controlling for covariates such as age, gender, and school characteristics. Similarly, Grissom (2005) observed poorer reading achievement for children who failed to achieve the FITNESSGRAM HFZ for BMI, relative to those who met the standard. Using mixed-model regression analyses, Welk et al. (2010) also indicated a negative association between the FITNESSGRAM-defined BMI and total academic performance after including other covariates such as age, gender, and financial need in the model.

Cottrell et al. (2007) observed that weight status significantly influenced children's academic achievement. Specifically, children within the "normal-weight" BMI category had the highest academic achievement in the area of mathematics, reading/language arts and science, followed by those within the category of "at risk of being overweight" BMI category, and then those in the "overweight" BMI category. Finally, children who were categorised into the "underweight" BMI category showed the lowest academic achievement according to the Centers for Disease Control and Prevention (CDC) BMI standards. Yet, after controlling for covariates including physical fitness, gender, age, financial need, and cardiovascular risk factors, children's weight status was not associated with their academic achievement. Considering that BMI has been observed to be inversely associated with cardiorespiratory fitness (Castelli et al., 2007; Cottrell et al., 2007), it is possible that weight status plays some role in the relationship between cardiorespiratory fitness and the academic performances. A similar weakened association of BMI to academic achievement was reported by Roberts et al. (2010), in which children exceeding the

Table 2. Studies examining the relationship between PF assessed by tests other than FITNESSGRAM and academic achievement.

Reference	Population characteristics	Assessment of PF components, methods	Academic test, academic subjects	Main results
de Greeff et al. (2014) the Netherlands	<i>N</i> :544 (Male = 47.4%) <i>M</i> _{age} : 8.0 ± 0.7 yrs	<i>Eurofit physical fitness test battery</i> : ASE: Sit-ups CRF: 20-m endurance shuttle run/ 10 × 5 m shuttle run Static strength: handgrip	math reading spelling	<i>Relationships between PF and AA</i> CRF : (+): math (+): spelling (for non-SDC children only)
Chomitz et al. (2009) US	<i>N</i> : 1841 (Male = 53.0%) Grade: 4, 6 ~ 8	TPF: (ASE, CRF, F, SA and UBSE) ASE: DNS BC: BMI (CDC) CRF: DNS F: DNS SA: DNS UBSE: DNS	MCAS : language arts (4 and 7 grade) math (4, 6 and 8 grade)	<i>Relationships between PF and AA (after controlling for BMI, sex, grade and SES)</i> : TPE : (+): % passed in language arts (+): % passed in math
Eveland-Sayers et al. (2009) US	<i>N</i> = 134 (Male = 54.5%) Age: 8 ~ 11 yrs Grade: 3 ~ 5	ASE: CU BC: BMI (CDC) CRF: O F: SR	Terra Nova test : math reading/ language arts	<i>Relationships between PF and AA</i> : CRF : (+): math Muscular fitness (ASE + F) : (+): math <i>Relationships between PF and AA (analysed for gender)</i> : CRF : (+): math (only girls) (+): reading (only girls)
Kwak et al. (2009) Sweden	<i>N</i> = 232 (Male = 48.3%) <i>M</i> _{age} : 16 ± 0.4 yrs Grade: 9	BC: Skinfold CRF: maximal power output (bicycle ergometer)	TAS: Sum of 17 subjects' grades	<i>Relationships between PF and AA</i> : CRF : (+): TAS (boys only)
Martin and Chalmers (2007) US	<i>N</i> = 5847 Grade: 3, 5, 6 and 8	<i>The President's Challenge test battery</i> : TPF: (ASE, CRF, F, SA, and UBSE) ASE: CU CRF: O F: The V-sit reach UBSE: PULL or FAH	ITBS : Average academic percentile scores (TAS: language arts, math and reading)	<i>Relationships between PF and AA</i> : TPB : (+):TAS

Notes: **ASE**: abdominal strength and endurance; **BC**: body composition; **BMI**: Body Mass Index; **CDC**: Centers for Disease Control and Prevention; **CU**: Curl-up test; **CRF**: cardiorespiratory fitness; **DNS**: did not specified; **F**: flexibility; **FAH**: Flexed-Arm Hang test; **ITBS**: Iowa Tests of Basic Skills; **MAge**: average age; **MCAS**: Massachusetts Comprehensive Assessment System ; **N**: number of total participants; **O**: One-Mile Run/ Walk test; **PULL**: Pull-Up test; **SDC**: socially disadvantaged children; **SR**: sit-and-reach test; **TAS**: total academic scores; **TPF**: total PF score; **UBSE**: upper body strength and endurance; (+): significant positive association between the physical fitness component and academic achievement; (-): significant negative association between the physical fitness component and academic achievement.

CDC-defined BMI standard had lower performance on mathematics, reading tests, and language tests compared to children within the CDC-recommended BMI range; however, after including cardiorespiratory fitness in the model, the association between BMI and academic achievement vanished. Finally, two other studies reported no statistically significant association between CDC-defined BMI-for-age and scholastic achievement (Eveland-Sayers et al., 2009; Wittberg et al., 2009).

Taken together, although an inverse association between BMI and scholastic performance has been reported in some studies, this association is typically weakened or absent after covariates are considered.

Composite measure of fitness. Although so far we have focused on how the individual components of health-related fitness may relate to academic achievement, an alternative, albeit complimentary, approach is to view the relationship between these domains from a global perspective representing the overall health of the organism by way of a composite measure of fitness. Although arguments could be made as to the best way to appropriately weight each of these components as they relate to physical health and well-being, the present literature's reliance on the FITNESSGRAM to assess multiple components (or zones) of health-related physical fitness offers the ability to utilise the number of HFZs in which an individual qualifies as being of healthy fitness as a more global measure of health-related physical fitness.

Within this literature, a positive association between composite measures of physical fitness and academic achievement has been observed (Blom et al., 2011; Castelli et al., 2007; Cottrell et al., 2007; Grissom, 2005), with superior academic scores being associated with the number of HFZs achieved. Specifically, positive associations have been reported for composite measures of fitness with reading and mathematics scores (Blom et al., 2011; Castelli et al., 2007; Cottrell et al., 2007; Grissom, 2005) and mean academic scores in social studies and science (Cottrell et al., 2007). Investigations, which have relied on measures other than the FITNESSGRAM to assess physical fitness, have also observed a positive association between global measures of fitness and academic achievement. After controlling for the effects of weight status, grade, socioeconomic status, gender, and ethnicity, Chomitz et al. (2009) found a positive association between composite physical fitness scores and achievement in the areas of English and mathematics, with a stronger relationship being observed for mathematics. The passing rate for English and mathematics tests was observed to increase by 24% and 38%, respectively, for each 1-unit increase in the number of fitness tests passed, which were similar to the findings of Blom et al. (2011), who reported the odds of passing a language arts and mathematic tests increased three and four times, respectively, with each additional HFZ of the FITNESSGRAM. Martin and Chalmers (2007) utilised a different approach, computing the mean fitness percentile across aerobic capacity, abdominal strength and endurance, flexibility, speed/agility, and upper body strength/endurance. This mean that fitness percentile measure was subsequently observed to positively relate to overall academic achievement reflected by the mean academic percentile score in reading, language arts, and mathematics.

Accordingly, despite the fact that not all investigations use the same metrics to compute overall physical fitness, this body of literature collectively supports a link between the overall fitness of a child and greater scholastic performance.

Health-related physical fitness and academic performance: ERP findings

Cardiorespiratory fitness. Investigations assessing the relation between fitness and neuroelectric indices of cognition have predominately focused on cardiorespiratory fitness. A number of previous investigations have assessed the relation between the P3 component and cardiorespiratory fitness, with higher fitness children exhibiting larger P3 amplitude and faster P3 latency relative to

lower fitness children (Hillman et al., 2005; Hillman, Buck, Themanson, Pontifex, & Castelli, 2009; Moore, Drollette, Scudder, Bharij, & Hillman, 2014; Stroth et al., 2009). Further, children with greater cardiorespiratory fitness appear better able to suppress extraneous neural operations to facilitate attentional processing, as indexed by the amplitude of the P3. That is, in response to the arithmetic verification task, Moore et al. (2014) observed that higher fitness children exhibited smaller P3 amplitude than lower fitness children when the answer of the arithmetic problem presented was incorrect and when the arithmetic problem was easy. Similarly, based upon their findings, Pontifex et al. (2011) indicated that higher fitness children were better able to flexibly increase the suppression of extraneous neural operations in order to facilitate attentional processing when the cognitive task became the most difficult, whereas lower fitness children were unable to do so.

In a recent investigation by Scudder et al. (2014), the association between cardiorespiratory fitness and the N400 and P600 ERP components was assessed in response to a sentence processing task. Across all conditions of the task, children with greater cardiorespiratory fitness exhibited superior semantic processing, as indexed by larger N400 amplitude and shorter latency. Higher fitness children also exhibited superior syntactic processing, as indexed by larger P600 amplitude. These findings suggest that cardiorespiratory fitness is associated with a superior ability to access a richer lexical-semantic network faster and to detect syntactic errors within a sentence, which may support superior language and reading skills – considered to be core predictors of later academic achievement in children (Lonigan, Burgess, & Anthony, 2000). Moore et al. (2014) also observed larger N400 amplitude in children with greater levels of cardiorespiratory fitness, relative to those with lower fitness levels, in response to an arithmetic verification task. Such findings suggest that children with higher levels of cardiorespiratory fitness are better able to extract meaning and relations related to mathematics problems than children with lower levels of cardiorespiratory fitness. Taken together, these findings with ERPs such as P3, N400, and P600 indicate that cardiorespiratory fitness is associated with core neurocognitive processes (i.e. the allocation of attentional resources, semantic, and syntactic processing) that are involved with scholastic performance.

Muscular strength, muscular endurance, and flexibility. Few studies have focused on the relationship between muscular strength, muscular endurance, flexibility, and ERPs in children. Chang, Tsai, Chen, and Hung (2013), as one exception, explored the impacts of motor movement ability on flanker task performance in children. They recruited 26 healthy kindergarten children and assigned these participants into either low intensity or moderate intensity coordinative exercise groups. Muscular strength and endurance and flexibility were assessed and the flanker task was conducted before and after the exercise intervention. The authors reported improvements in muscular strength, muscular endurance, and flexibility, as well as the performance of the flanker task, after the exercise intervention. Additionally, they reported larger P3 amplitude and shorter P3 latency after the exercise intervention, suggesting that children who improved in muscular strength and flexibility through participating in a coordinative exercise programme might increase processing speed and their ability to allocate attentional resources. The study provides the possible linkage between muscular strength, muscular endurance, flexibility, and cognitive function, but more studies are needed for clarifying the issue.

Body composition. Studies have observed that obese individuals manifest with alterations in neurocognitive processes relative to individuals in the healthy BMI range. Specifically, Kamijo et al. (2012) examined the difference between obese and healthy weight children in the N200 (also called N2) and P3 ERP components in response to the Go/NoGo task. Beyond poorer performance during the NoGo condition, which required greater amounts of executive control, obese children also demonstrated reduced P3 amplitude over frontal electrode sites relative to healthy weight children suggesting less efficient attentional resource allocation. Further, obese children demonstrated larger N2 amplitude relative to healthy weight children, suggesting that obese

children might have less efficient conflict resolution ability, poorer inhibitory control, and/or delayed development of the prefrontal cortex relative to healthy weight children (Kamijo et al., 2012). Similarly, Tascilar et al. (2011) observed smaller P3 amplitude and longer P3 latency for obese children relative to healthy children. Further, within the group of obese children, insulin resistance was associated with further reductions in P3 amplitude and protracted P3 latency (Tascilar et al., 2011).

Weight status has also been linked to children's action monitoring, with obese children demonstrating smaller amplitude of the error-related negativity (ERN) and poorer post-error response accuracy during the modified flank task, relative to healthy weight children (Kamijo et al., 2014). As the ERN provides an index of action monitoring and signalling for additional top down control, these findings suggest that obese children have an impaired ability to regulate their interactions with the environment following execution of an error. Taken together, these findings might suggest that childhood obesity is associated with a decreased ability to flexibly modulate high-level cognitive operations to meet the demands of the task and poorer inhibitory control, which may result in impaired academic achievement.

Composite measures of fitness. To the best of our knowledge, no research has been conducted to specifically examine the association between composite measures of fitness and ERPs.

Future directions

Despite the general trend for an association between multiple components of health-related physical fitness and both scholastic achievement and underlying neurocognitive function, it is clear that more research is required. Accordingly, several potential approaches for future research are suggested in order to deepen our understanding of these relationships.

First, investigating potential dose–response relationships between health-related physical fitness components and academic achievement in children and adolescents is warranted in future research. Further research is also necessary to determine the appropriateness of a linear model relative to a higher order model which may indicate a relative threshold for differences as a function of health-related fitness components. Finally, given the promising findings of the associations between health-related physical fitness and children's scholastic performance, as well as the fact that only a small number of interventions (Dwyer, Coonan, Leitch, Hetzel, & Baghurst, 1983; Hollar et al., 2010; Sallis et al., 1999) and an even smaller number of randomised clinical trials (Donnelly et al., 2013) have been conducted on this topic, it may be of interest for future research to utilise an interventional experimental design (or even a randomised clinical trials design) to establish the causal inference as well as to further differentiate the specific contributions of each health-related physical fitness component toward children's academic performance.

To date, the vast majority of research studies assessing health-related physical fitness and academic achievement in children has utilised field-based assessments, and different measurement methods might influence the observed relation between fitness and academic achievement. For instance, Dwyer et al. (2001) examined the relationship between children's cardiorespiratory fitness, which was assessed through field tests (i.e. the 1.6 km run) and laboratory methods (i.e. physical work capacity, the PWC₁₇₀), and scholastic rating scores from a sample of 7961, Australian schoolchildren aged 7–15 years. It was of interest to note that, while cardiorespiratory fitness measured by the PWC₁₇₀ showed no association with the scholastic rating, a significant association was found when cardiorespiratory fitness was assessed using the 1.6-km run (Dwyer et al., 2001). This difference between these two measures raises the question with regard to potential confounding factors such as social motivation when fitness assessed in the field tests, and suggests that the methods of measurement might influence the associations.

Relatedly, there might be differences in findings for body mass as a function of the measurement tool. Although measuring BMI is safe, simple, relatively low cost, and efficient as compared to using more sophisticated methods such as dual-energy x-ray absorptiometry and densitometry for body composition measure, it provides less information about the body fat distribution (Ganley et al., 2011). As potentially differential association of body fat distribution and BMI with cortical structures has been reported (Climie et al., 2015; Veit et al., 2014), considering measures of body composition that could characterise the body fat distribution might be helpful in explaining the body composition and scholastic performance relationship in future research. Last but not least, although several neuroelectric indices of neuro-cognition have been examined in relation to cardiorespiratory fitness, relatively few investigations have been conducted regarding the influence of muscular fitness and body composition. Accordingly, further research in these areas is necessary in order to better understand how these fitness components may impact neurocognitive processes which underlie more global cognitive processes such as scholastic achievement.

Conclusion

Collectively, evidence from the present review has highlighted a differential relationship between components of health-related fitness relative to academic achievement and underlying neurocognitive processes. Although global measures of health-related physical fitness appear to positively associate with academic achievement in the majority of academic subjects such as mathematics, reading/language arts, science, and social studies; components of health-related physical fitness appear to be differentially associated with academic achievement. Indeed, cardiorespiratory fitness appears to have a positive association with multiple scholastic areas as well as neurocognitive processes involved with the allocation of attentional resources and semantic and syntactic processing that may underlie scholastic performance. In contrast, BMI appears to be negatively related to the allocation of attentional resources and action-monitoring processes. However, the relationship with scholastic achievement is dramatically reduced and sometimes becomes non-significant once researchers have controlled for demographic variables (e.g. fitness). In the research looking at BMI and neurocognitive measures, covariates have typically not been controlled; hence, further study is needed. While more studies are required to further our understanding of this relationship, based upon the current findings of a positive association between the majority of health-related physical fitness components and scholastic achievement in children and adolescents, it might be warranted for school educators, in company with exercise professionals, to design and include physical fitness enhancement programmes as plans for young children to help ensure scholastic success.

Funding

This research was supported by a portion of a grant from the Ministry of Science and Technology in Taiwan to Yu-Kai Chang [NSC 102-2410-H-179-014-MY3].

References

- American College of Sports Medicine. (2010). *ACSM's health-related physical fitness assessment manual* (Kaminsky, L. A. Ed., 3rd ed.). Philadelphia, PA: Lippincott Williams & Wilkins Health.
- Biddle, S. J., & Asare, M. (2011). Physical activity and mental health in children and adolescents: A review of reviews. *British Journal of Sports Medicine*, 45(11), 886–895. doi:10.1136/bjsports-2011-090185

- Blom, L. C., Alvarez, J., Zhang, L., & Kolbo, J. (2011). Associations between health-related physical fitness, academic achievement and selected academic behaviors of elementary and middle school students in the State of Mississippi. *ICHPER-SD Journal of Research*, 6(1), 13–19.
- Castelli, D. M., Hillman, C. H., Buck, S. M., & Erwin, H. E. (2007). Physical fitness and academic achievement in third- and fifth-grade students. *Journal of Sport and Exercise Psychology*, 29(2), 239–252.
- Castillo-Garzon, M. J., Ruiz, J. R., Ortega, F. B., & Gutierrez-Sainz, A. (2007). A mediterranean diet is not enough for health: Physical fitness is an important additional contributor to health for the adults of tomorrow. *World Review of Nutrition and Dietetics*, 97, 114–138. doi:10.1159/000097913
- Chang, Y. K., Tsai, Y. J., Chen, T. T., & Hung, T. M. (2013). The impacts of coordinative exercise on executive function in kindergarten children: An ERP study. *Experimental Brain Research*, 225(2), 187–196. doi:10.1007/s00221-012-3360-9
- Chomitz, V. R., Slining, M. M., McGowan, R. J., Mitchell, S. E., Dawson, G. F., & Hacker, K. A. (2009). Is there a relationship between physical fitness and academic achievement? Positive results from public school children in the northeastern United States. *Journal of School Health*, 79(1), 30–37. doi:10.1111/j.1746-1561.2008.00371.x
- Climie, R. E. D., Moran, C., Callisaya, M., Blizzard, L., Sharman, J. E., Venn, A., ... Srikanth, V. (2015). Abdominal obesity and brain atrophy in Type 2 diabetes mellitus. *PLoS One*, 10(11), e0142589. doi:10.1371/journal.pone.0142589
- Coe, D. P., Pivarnik, J. M., Womack, C. J., Reeves, M. J., & Malina, R. M. (2006). Effect of physical education and activity levels on academic achievement in children. *Medicine and Science in Sports and Exercise*, 38(8), 1515–1519.
- Cottrell, L. A., Northrup, K., & Wittberg, R. (2007). The extended relationship between child cardiovascular risks and academic performance measures. *Obesity (Silver Spring)*, 15(12), 3170–3177. doi:10.1038/oby.2007.377
- van Dinternen, R., Arns, M., Jongsma, M. L., & Kessels, R. P. (2014). P300 development across the lifespan: A systematic review and meta-analysis. *PLoS One*, 9(2), e87347. doi:10.1371/journal.pone.0087347
- Donnelly, J. E., Greene, J. L., Gibson, C. A., Sullivan, D. K., Hansen, D. M., Hillman, C. H., ... Washburn, R. A. (2013). Physical activity and academic achievement across the curriculum (A + PAAC): Rationale and design of a 3-year, cluster-randomized trial. *BMC Public Health*, 13, 307. doi:10.1186/1471-2458-13-307
- Dwyer, T., Coonan, W. E., Leitch, D. R., Hetzel, B. S., & Baghurst, R. A. (1983). An investigation of the effects of daily physical activity on the health of primary school students in South Australia. *International Journal of Epidemiology*, 12(3), 308–313.
- Dwyer, T., Sallis, J. F., Blizzard, L., Lazarus, R., & Dean, K. (2001). Relation of academic performance to physical activity and fitness in children. *Pediatric Exercise Science*, 13(3), 225–237.
- Erickson, K. I., Hillman, C. H., & Kramer, A. F. (2015). Physical activity, brain, and cognition. *Current Opinion in Behavioral Sciences*, 4, 27–32.
- Esteban-Cornejo, I., Tejero-Gonzalez, C. M., Martinez-Gomez, D., Cabanas-Sanchez, V., Fernandez-Santos, J. R., Conde-Caveda, J., ... Veiga, O. L. (2014). Objectively measured physical activity has a negative but weak association with academic performance in children and adolescents. *Acta Paediatrica*. doi:10.1111/apa.12757
- Eveland-Sayers, B. M., Farley, R. S., Fuller, D. K., Morgan, D. W., & Caputo, J. L. (2009). Physical fitness and academic achievement in elementary school children. *Journal of Physical Activity & Health*, 6(1), 99–104.
- Ganley, K. J., Paterno, M. V., Miles, C., Stout, J., Brawner, L., Girolami, G., & Warren, M. (2011). Health-related fitness in children and adolescents. *Pediatric Physical Therapy*, 23(3), 208–220. doi:10.1097/PEP.0b013e318227b3fc
- de Greeff, J. W., Hartman, E., Mullender-Wijnsma, M. J., Bosker, R. J., Doolaard, S., & Visscher, C. (2014). Physical fitness and academic performance in primary school children with and without a social disadvantage. *Health Education Research*, 29(5), 853–860. doi:10.1093/her/cyu043
- Grisson, J. (2005). Physical fitness and academic achievement. *Journal of Exercise Physiology*, 8(1), 11–25.
- Hansen, D. M., Herrmann, S. D., Lambourne, K., Lee, J., & Donnelly, J. E. (2014). Linear/nonlinear relations of activity and fitness with children's academic achievement. *Medicine and Science in Sports and Exercise*, 46(12), 2279–2285. doi:10.1249/mss.0000000000000362
- Hillman, C. H., Buck, S. M., Themanson, J. R., Pontifex, M. B., & Castelli, D. M. (2009). Aerobic fitness and cognitive development: Event-related brain potential and task performance indices of executive control in preadolescent children. *Developmental Psychology*, 45(1), 114–129. doi:10.1037/a0014437

- Hillman, C. H., Castelli, D. M., & Buck, S. M. (2005). Aerobic fitness and neurocognitive function in health preadolescent children. *Medicine and Science in Sports and Exercise*, 37(11), 1967–1974.
- Hillman, C. H., Pontifex, M. B., Motl, R. W., O’Leary, K. C., Johnson, C. R., Scudder, M. R., ... Castelli, D. M. (2012). From ERPs to academics. *Developmental Cognitive Neuroscience*, 2(Suppl. 1), S90–S98. doi:10.1016/j.dcn.2011.07.004
- Hirsh, J. B., & Inzlicht, M. (2010). Error-related negativity predicts academic performance. *Psychophysiology*, 47(1), 192–196. doi:10.1111/j.1469-8986.2009.00877.x
- Hollar, D., Messiah, S. E., Lopez-Mitnik, G., Hollar, T. L., Almon, M., & Agatston, A. S. (2010). Effect of a two-year obesity prevention intervention on percentile changes in body mass index and academic performance in low-income elementary school children. *American Journal of Public Health*, 100(4), 646–653. doi:10.2105/AJPH.2009.165746
- Hruby, T., & Marsalek, P. (2003). Event-related potentials – the P3 wave. *Acta Neurobiologiae Experimentalis*, 63(1), 55–63.
- Janssen, I., & Leblanc, A. G. (2010). Systematic review of the health benefits of physical activity and fitness in school-aged children and youth. *International Journal of Behavioral Nutrition and Physical Activity*, 7, 40. doi:10.1186/1479-5868-7-40
- Kamijo, K., Pontifex, M. B., Khan, N. A., Raine, L. B., Scudder, M. R., Drollette, E. S., ... Hillman, C. H. (2012). The association of childhood obesity to neuroelectric indices of inhibition. *Psychophysiology*, 49(10), 1361–1371. doi:10.1111/j.1469-8986.2012.01459.x
- Kamijo, K., Pontifex, M. B., Khan, N. A., Raine, L. B., Scudder, M. R., Drollette, E. S., ... Hillman, C. H. (2014). The negative association of childhood obesity to cognitive control of action monitoring. *Cerebral Cortex*, 24(3), 654–662. doi:10.1093/cercor/bhs349
- Keeley, T. J., & Fox, K. R. (2009). The impact of physical activity and fitness on academic achievement and cognitive performance in children. *International Review of Sport and Exercise Psychology*, 2(2), 198–214.
- Khalifian, N., Stites, M. C., & Laszlo, S. (2015). Relationships between event-related potentials and behavioral and scholastic measures of reading ability: A large-scale, cross-sectional study. *Developmental Science*. doi:10.1111/desc.12329
- Kwak, L., Kremers, S. P., Bergman, P., Ruiz, J. R., Rizzo, N. S., & Sjoström, M. (2009). Associations between physical activity, fitness, and academic achievement. *Journal of Pediatrics*, 155(6), 914–918.e1. doi:10.1016/j.jpeds.2009.06.019
- Lonigan, C. J., Burgess, S. R., & Anthony, J. L. (2000). Development of emergent literacy and early reading skills in preschool children: Evidence from a latent-variable longitudinal study. *Developmental Psychology*, 36(5), 596–613.
- Martin, L. T., & Chalmers, G. R. (2007). The relationship between academic achievement and physical fitness. *Physical Educator*, 64(4), 214–221.
- Moore, R. D., Drollette, E. S., Scudder, M. R., Bharij, A., & Hillman, C. H. (2014). The influence of cardiorespiratory fitness on strategic, behavioral, and electrophysiological indices of arithmetic cognition in preadolescent children. *Frontiers in Human Neuroscience*, 8, 258. doi:10.3389/fnhum.2014.00258
- Nieuwenhuis, S., Ridderinkhof, K. R., Blom, J., Band, G. P., & Kok, A. (2001). Error-related brain potentials are differentially related to awareness of response errors: Evidence from an antisaccade task. *Psychophysiology*, 38(5), 752–760.
- Ortega, F. B., Ruiz, J. R., Castillo, M. J., & Sjoström, M. (2008). Physical fitness in childhood and adolescence: A powerful marker of health. *International Journal of Obesity (Lond)*, 32(1), 1–11. doi:10.1038/sj.ijo.0803774
- Polich, J. (2007). Updating P300: An integrative theory of P3a and P3b. *Clinical Neurophysiology*, 118(10), 2128–2148. doi:10.1016/j.clinph.2007.04.019
- Pontifex, M. B., Raine, L. B., Johnson, C. R., Chaddock, L., Voss, M. W., Cohen, N. J., ... Hillman, C. H. (2011). Cardiorespiratory fitness and the flexible modulation of cognitive control in preadolescent children. *Journal of Cognitive Neuroscience*, 23(6), 1332–1345. doi:10.1162/jocn.2010.21528
- Rachele, J. N., McPhail, S. M., Washington, T. L., & Cuddihy, T. F. (2012). Practical physical activity measurement in youth: A review of contemporary approaches. *World Journal of Pediatrics*, 8(3), 207–216. doi:10.1007/s12519-012-0359-z
- Roberts, C. K., Freed, B., & McCarthy, W. J. (2010). Low aerobic fitness and obesity are associated with lower standardized test scores in children. *Journal of Pediatrics*, 156(5), 711–718.e1. doi:10.1016/j.jpeds.2009.11.039

- Ruiz, J. R., Castro-Pinero, J., Artero, E. G., Ortega, F. B., Sjostrom, M., Suni, J., & Castillo, M. J. (2009). Predictive validity of health-related fitness in youth: A systematic review. *British Journal of Sports Medicine*, *43*(12), 909–923. doi:10.1136/bjism.2008.056499
- Sallis, J. F., McKenzie, T. L., Kolody, B., Lewis, M., Marshall, S., & Rosengard, P. (1999). Effects of health-related physical education on academic achievement: Project SPARK. *Research Quarterly for Exercise and Sport*, *70*(2), 127–134.
- Scudder, M. R., Federmeier, K. D., Raine, L. B., Direito, A., Boyd, J. K., & Hillman, C. H. (2014). The association between aerobic fitness and language processing in children: Implications for academic achievement. *Brain and Cognition*, *87*(0), 140–152. doi:10.1016/j.bandc.2014.03.016
- Sibley, B. A., & Etnier, J. L. (2003). The relationship between physical activity and cognition in children: A meta-analysis. *Pediatric Exercise Science*, *15*(3), 243–256.
- Stroth, S., Kubesch, S., Dieterle, K., Ruchow, M., Heim, R., & Kiefer, M. (2009). Physical fitness, but not acute exercise modulates event-related potential indices for executive control in healthy adolescents. *Brain Research*, *1269*, 114–124. doi:10.1016/j.brainres.2009.02.073
- Tascilar, M. E., Turkkahraman, D., Oz, O., Yucel, M., Taskesen, M., Eker, I., ... Ulas, U. H. (2011). P300 auditory event-related potentials in children with obesity: Is childhood obesity related to impairment in cognitive functions? *Pediatric Diabetes*, *12*(7), 589–595. doi:10.1111/j.1399-5448.2010.00748.x
- Tomporowski, P. D., Lambourne, K., & Okumura, M. S. (2011). Physical activity interventions and children's mental function: An introduction and overview. *Preventive Medicine*, *52*(Suppl. 1), S3–S9. doi:10.1016/j.ypmed.2011.01.028
- Veit, R., Kullmann, S., Heni, M., Machann, J., Haring, H. U., Fritsche, A., & Preissl, H. (2014). Reduced cortical thickness associated with visceral fat and BMI. *NeuroImage: Clinical*, *6*, 307–311. doi:10.1016/j.nicl.2014.09.013
- Weber-Fox, C., Davis, L. J., & Cuadrado, E. (2003). Event-related brain potential markers of high-language proficiency in adults. *Brain and Language*, *85*(2), 231–244.
- Welk, G. J., Jackson, A. W., Morrow, J. R., Jr., Haskell, W. H., Meredith, M. D., & Cooper, K. H. (2010). The association of health-related fitness with indicators of academic performance in Texas schools. *Research Quarterly for Exercise and Sport*, *81*(3 Suppl.), S16–S23.
- Welk, G. J., & Meredith, M. D. (Eds.). (2008). *Fitnessgram®/Activitygram® Reference Guide* (3rd ed.). Dallas, TX: The Cooper Institute.
- Wittberg, R. A., Northrup, K. L., & Cottrell, L. A. (2009). Children's physical fitness and academic performance. *American Journal of Health Education*, *40*(1), 30–36.