Influence of physical fitness on cognitive and academic performance in adolescents: A systematic review from 2005–2015

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Influence of physical fitness on cognitive and academic performance in adolescents: A systematic review from 2005–2015

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ABSTRACT

Background: The aim of this systematic review was to investigate the association of different components of physical fitness on cognitive performance (CP) and academic performance (AP) in adolescents, taking into account potential confounders.

Method: Studies were identified in four databases (Pubmed, SportDiscus, Web of Science, and ProQuest) from January 2005 through to January 2015. A total of 21 articles met the inclusion criteria. Results: 8 studies showed association between physical fitness and CP, and 11 studies with AP. Cardiorespiratory fitness, speed-agility, motor coordination, and perceptual-motor skill are the highest measures associated with CP and AP. However, the findings on strength and flexibility are unclear. Finally, 62% of the 21 studies used confounders. The most controlled confounder were socioeconomic status, fatness, pubertal status, sex, and age.

Conclusion: Fitness is associated with higher CP and AP. More research is needed in order to understand the causes of the differential effect of physical fitness components on CP and AP.

ARTICLE HISTORY
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KEYWORDS
physical fitness; cognitive performance; academic performance; confounder; adolescents; systematic review

Introduction

Physical fitness refers to the full range of physical qualities of cardiorespiratory fitness (CRF), muscular strength, speed-agility, coordination, flexibility, or body composition (Castro-Piñero et al., 2010; Ruiz et al., 2009). Substantial data have demonstrated the role of physical fitness for improving the musculoskeletal system (Ortega, Ruiz, Castillo, & Sjöström, 2008), preventing psychological risk factors (including depression, anxiety, and psychological stress) (Caputo & Simon, 2013; Lavie, Milani, O'Keefe, & Lavie, 2011), decreasing the risk of cardiometabolic diseases (Ortega et al., 2008), and reducing the risk of all-causes of premature mortality (Ortega, Silventoinen, Tynelius, & Rasmussen, 2012). Furthermore, in recent years a growing number of studies have also shown the relationship between physical fitness and cognitive performance (CP) and academic performance (AP) in children (Castelli, Hillman, Buck, & Erwin, 2007; Haapala, 2013; Torrijos-Niño et al., 2014) and adolescents (Ardoy et al., 2014; Chen, Fox, Ku, & Taun, 2013; Coe, Peterson, Blair, Schutten, & Peddie, 2013).
CP is affected by the inhibitory control and executive functions, which are the factors responsible for the maintenance of information in working memory, planning and mental organisation, selective attention, and behaviour control (Diamond, 2013; Haapala, 2013). Physical fitness could optimise the above functions because it promotes an increase of cerebral blood flow and synaptic plasticity (Pareja-Galeano et al., 2013), and an increase in the brain-derived neurotrophic factor (BDNF) levels that support the survival and growth of neurons (Noakes & Spedding, 2012; Wrann et al., 2013). These physiological adaptations could improve learning ability (Chaddock-Heyman et al., 2014a; Wrann et al., 2013) and may have a positive influence on subsequent AP (Chaddock-Heyman et al., 2014a; Tomporowski, McCullick, Pendleton, & Pesce, 2015).

AP refers to adolescents’ success in secondary school, measured by grade point averages or by the child meeting standardised performance tests (Haapala, 2013). In addition to CP, other factors such as teachers’ assessment of student attitudes, interest, participation, and attendance in class can influence on AP (Gutiérrez & López, 2012). Likewise, AP may be mediated by other socioeconomic variables, such as education level and occupation of parents (Castillo et al., 2011), family influence, sociocultural context, teacher opinion (Keeley & Fox, 2009), duration of breastfeeding (Vicenta et al., 2015), general emotional well-being of the child (Morales & López-Zafría, 2009), self-perception of competence, and setting goals and study strategies for young people (Caso-Niebla & Hernández-Guzmán, 2007). Therefore, to study the association of physical fitness with cognition, it is essential to separate CP from AP. In addition, it is necessary to know the differential result compared to other variables, such as age, sex, BMI and socioeconomic status (SES), as these could influence the results of association due to their importance during adolescence. In fact, the main limitation of the current research is that there is no consensus about the most influential confounders on the association between physical fitness and AP (Esteban-Cornejo et al., 2014a).

Longitudinal and cross-sectional studies that analyse the relationship of different components of physical fitness with CP and AP have proliferated over the last decade (Aberg et al., 2009; Castelli et al., 2007; Esteban-Cornejo et al., 2014a; Hillman, Buck, Themanson, Pontifex, & Castelli, 2009; Van Dusen, Kelder, Kohl, Ranjit, & Perry, 2011; Wittberg, Northrup, & Cottrel, 2008). However, the results are inconclusive, and we are not aware of any review that has specifically compared the influence of each physical fitness component—CRF, muscular strength, speed-agility, motor coordination, flexibility, or body composition—with CP and AP in adolescents.

On the other hand, previous reviews have studied the association of physical activity (PA) with CP and AP in children and adolescents and have produced divergent results (Chaddock-Heyman, Hillman, Cohen, & Kramer, 2014b; Esteban-Cornejo, Tejero-Gonzalez, Sallis, & Veiga, 2015a; Fedewa & Ahn, 2011; Haapala, 2013; Rasberry et al., 2011; Singh, Uijtdewilligen, Twisk, van Mechelen, & Chinapaw, 2012; Tomporowski, Davis, Miller, & Naglieri, 2008). Possible causes are that most of the evidence comes from studies that do not recognise the multifactorial nature of the PA (Esteban-Cornejo et al., 2015a; Haapala, 2013). PA in adolescents is a very wide term that can refer equally to participation in sports (Bradley, Keane, & Crawford, 2013), PE classes (Ardoy et al., 2014), extracurricular PA (Esteban-Cornejo et al., 2014b), active commuting to school (Martínez-Gómez et al., 2011), moderate to vigorous physical activity (MVPA) (Sylvöja, Tamminen, Ahonen, Kankaanpää, & Kantomaa, 2014; Van Dijk, De Groot, Savelberg, Van Acker, & Kirschner, 2014), or physical fitness (Haapala, 2013).
The question of this study is the following: ‘Do the components of physical fitness influence on CP and AP in secondary school adolescents?’ This review focuses on adolescence because this is a key stage for consolidating healthy lifestyles and increasing physical fitness (Martínez-Gómez et al., 2011; Ortega et al., 2008). Furthermore, during this period there is a higher grade of brain plasticity (Romeo & McEwen, 2006) that is decisive for stimulating cognitive function (Ardoy et al., 2014). Understanding low/high physical fitness as a predictor of CP and AP could clarify the debate about the potential of physical fitness on cognition and decisions about the level of integration in education systems.

Therefore, the objective of the present systematic review was to investigate the associations of different components of physical fitness with CP and AP in adolescents. Additionally, this paper also reviewed potential mediators and moderators (i.e., socioeconomic variables, fatness or sex) that could influence the relationship of physical fitness with CP and AP.

Method

The study was designed following the structure and recommendation of other systematic reviews (Castro-Piñero et al., 2010; Esteban-Cornejo et al., 2015a; Ruiz et al., 2009) and the treatment used by PRISMA guidance for reports and studies (Moher, Liberati, Tetzlaff, & Altman, 2009).

Search limits

A comprehensive search of 4 databases of literature (PubMed, SportDiscus, Web of Science, and ProQuest) from January 2005 through to January 2015 was undertaken. Additionally, reference lists of the selected papers were reviewed. The principal categories of search terms were identified and used in different combinations:

1. Physical fitness (physical education, physical fitness, cardiovascular, aerobic, musculoskeletal, strength, speed, agility, ability, coordination, flexibility).

Table 1 shows the main terms used in the search for each category.

Selection criteria

The relevant papers selected for inclusion in the review were checked against the following criteria:

1. The study was a full text report published in a peer-reviewed journal.
2. The study population was a healthy community-based population.
3. The study included papers written in English, with a population of high-school adolescents between 13 and 18 years of age.
4. The study used a cross-sectional, longitudinal, or interventional design.
5. There were no exclusion criteria with regard to ethnic origin.
Information on author, title, aim, sample size, age, study year, country, design, physical fitness measurement, CP and AP measurement, confounders, and main results/conclusions was extracted from all studies. The search process was carried out by three independent reviewers (ARA, AGC, EJML). The reviewers read every title and all the abstracts, and a consensus meeting was arranged to resolve any differences between them. The results of the most recent reviews were summarised first, then studies that were potentially relevant for the selected topics were screened for retrieval.

Quality assessment and level of evidence

The quality assessment of the question was carried out on the basis of other standardised assessment lists (Castro-Piñero et al., 2010; Ruiz et al., 2009) and on our selection criteria. The list included 6 items (A-F) on peer-reviewed journal, population, measurements, design, confounders, and report of the results. Each item was rated as ‘2’ (fully reported), ‘1’ (moderately reported) or ‘0’ (not reported or unclear). For all studies, a total quality score was calculated by counting the number of positive items (a total score between 0 and 12). Three levels of evidence were constructed. Studies were defined as of high quality (HQ) if they had a total score of 9 or higher. A total score of 5 to 8 was defined as of medium quality (MQ), and a score of less than 5 was defined as low quality (LQ) (see Table 2).
**Results**

**General findings**

The flow of search results through the systematic review process is shown in Figure 1. After removal of duplicates and those excluded at title or abstract level, a total of 88 papers were retrieved. These potential studies were reviewed according to the selection criteria, on the basis of which, a total of 67 articles were excluded. Finally, 21 articles were included in the systematic review.

A detailed analysis of these studies showed that 10 were cross-sectional (48%) (Bass, Brown, Laurson, & Coleman, 2013; Coe et al., 2013; Esteban-Cornejo et al., 2014a; Janak et al., 2014; Kwak et al., 2009; Morales, González, Guerra, Virgili, & Unnithan, 2011; Planinsec & Pisot, 2006; Ruiz et al., 2010; Sardinha, Marques, Martins, Palmeira, & Minderico, 2014; Welk et al., 2010), 4 were longitudinal with cohorts (19%) (Bezold et al., 2014; Chen et al., 2013; Kantomaa et al., 2013; London & Castrechini, 2011), 1 was cross-sectional and longitudinal with cohort (5%) (Aberg et al., 2009), and 6 were intervention studies (29%) (Ardoy et al., 2014; Budde, Voelcker-Rehage, Pietrałyk-Kendziorra, Ribeiro, & Tidow, 2008; Hogan et al., 2013; Soga, Shishido, & Nagatomi, 2015; Stroth et al., 2009; Travlos, 2010). Ardoy et al. (2014), Budde et al. (2008), Soga et al. (2015), used a group-randomised controlled trial. However, Hogan et al. (2013), Stroth et al. (2009); and Travlos, 2010 used a non-randomised controlled trial. With regard to quality assessment, 17 papers were of high quality and 4 of medium quality (Table 2). This review includes

<table>
<thead>
<tr>
<th>Authors and variables</th>
<th>A</th>
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<th>Total score</th>
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<td>Kwak et al. (2009). Fitness and AP</td>
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<td>Ruiz et al. (2010). PA, fitness, weight status, and CP</td>
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<td>London and Castrechini (2011). Fitness and AP</td>
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<td>Hogan et al. (2013). Fitness, acute aerobic exercise and CP</td>
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<td>Ardoy et al. (2014). PE class, fitness and, CP and AP</td>
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<td>Bezold et al. (2014). Fitness and AP</td>
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<td>Janak et al. (2014). Fitness and AP</td>
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<td>Esteban-Cornejo et al. (2014a). Fitness and AP</td>
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<td>Sardinha et al. (2014). Fitness, fatness and AP</td>
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<td>Soga et al. (2015). Executive function and acute moderate aerobic exercise</td>
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Note: Rating for total score: high quality (HQ) = 9–12; medium quality (MQ) = 5–8; low quality (LQ) = 0–4. CRF = Cardiorespiratory Fitness. AP = Academic Performance. CP = Cognitive Performance. PA = Physical Activity. PE = Physical Education. A: The study was a full text report published in a peer-reviewed journal. B: The study population was healthy. C: The selected physical fitness, cognitive and AP outcomes were clearly described. D: Population was of high-school adolescents between 13 and 18 years of age. E: The study had a cross-sectional, longitudinal or interventional design. F: Data was adjusted for confounders.
data from 3,910,791 individuals, and the sample size of the studies varied from 30 (Hogan et al., 2013) to 2,550,144 (Janak et al., 2014) participants. The samples were from 10 different countries: 1 study was conducted in Slovenia (Planinsec & Pisot, 2006), 3 in Germany (Budde et al., 2008; Hogan et al., 2013; Stroth et al., 2009), 2 in Sweden (Aberg et al., 2009; Kwak et al., 2009), 1 in Greece (Travlos, 2010), 6 in the USA (Bass et al., 2013; Bezold et al., 2014; Coe et al., 2013; Janak et al., 2014; London & Castrechini, 2011; Welk et al., 2010), 4 in Spain (Ardoy et al., 2014; Esteban-Cornejo et al., 2014a; Morales et al., 2011; Ruiz et al., 2010), 1 in Taiwan (Chen et al., 2013), 1 in Finland (Kantomaa et al., 2013), 1 in Portugal (Sardinha et al., 2014), and 1 in Japan (Soga et al., 2015). Detailed information about all the studies is presented in Table 3.

Physical fitness, cognitive performance, and academic performance measurement

Physical fitness measures used in each study are shown in Table 3: 20 studies used objective measures to assess physical fitness, and only 1 study used another measure (parent-reported motor function) (Kantomaa et al., 2013); 17 studies assessed CRF (Aberg et al., 2009; Ardoy et al., 2014; Bass et al., 2013; Bezold et al., 2014; Chen et al., 2013; Coe et al., 2013; Esteban-Cornejo et al., 2014a; Hogan et al., 2013; Janak et al., 2014; Kwak
<table>
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<tr>
<th>Authors and variables</th>
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<th>Physical fitness measures</th>
<th>CP and AP measures</th>
<th>Results</th>
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<tr>
<td>Planinsec and Pisot (2006). Motor coordination and intelligence level</td>
<td>Cross-sectional / Nothing / —</td>
<td>550 / 13.1 years / Slovenia</td>
<td>Motor coordination across eight tests: (a) coordination of movement in rhythm (tests: drumming with the hands, drumming with the hands and feet); (b) hand-eye coordination (test: match juggling); (c) whole-body coordination (tests: polygon backward, climbing and descending); (d) performance of complex coordination movements (tests: running while changing directions, running around two stands with obstacles, running, rolling, crawling).</td>
<td>Intelligence was carried out with test TN-20. This test is intended to measure fluid intelligence, i.e., the general neurophysiologic capacity of the central nervous system for information processing.</td>
<td>Results showed differences between the above- and below-average intelligence groups in: drumming with the hands, drumming with the hands and feet, match juggling, polygon backward running while changing directions, running around two stands with obstacles, and running, rolling, and crawling. In all these tests the above-average intelligence group achieved better results (p &lt; .05). There were no significant differences between above- and below-average intelligence groups in the motor coordination test of climbing and descending (p &gt; .05). Consequently these results support the demand for more acute coordinative exercise in schools.</td>
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<tr>
<td>Budde et al. (2008). Coordinative exercise and attentional performance</td>
<td>Interventional / Heart rate / 10 min</td>
<td>115 / 13–16 years / Germany</td>
<td>Two groups: Experimental group: 10 min of coordinative exercises, within these exercises different bilateral coordinative abilities were stressed within short periods of time: for example, the ability to balance, to react, to adjust, and to differentiate. Control group: 10 min of a normal sport lesson at a moderate intensity without any specific coordinative request.</td>
<td>Neuropsychological performance assessed in the areas of attention and concentration using the d2-test.</td>
<td>Coordinative exercise was more effective in completing the concentration and attention task (p &lt; .01). With the heart rate being the same in both groups, authors assume that the coordinative character of the exercise might be responsible for the significant differences. Results were achieved with students who practise sport every day (25–30 h per week). Consequently these results support the demand for more acute coordinative exercise in schools.</td>
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</table>
Aberg et al. (2009). CRF and cognition
Cross-sectional and longitudinal / conscription year, conscription test centre, father’s education, and mother’s education / 3 years
1,221,727 Swedish male subjects / 15–18 years / Sweden
CRF measured by ergometer cycling. Isometric muscle strength was measured by knee extension, elbow flexion, and handgrip.
Cognitive tests: logical performance test, verbal test of synonyms and opposites, test of visuospatial/geometric perception, and technical/mechanical skills including mathematical/physics problems. Performance on all 4 tests was combined to obtain a global intelligence (general cognitive ability).
CRF, not muscular strength, at age 18 years is associated with CP. Associations between CRF and CP remained even after adjusting for relevant confounders. Change in CRF between ages 15 and 18 years predicted global intelligence at age 18 years. Similar results were obtained for logical, verbal, visuospatial, and technical scores. Moreover, CRF during early adulthood predicted SES and educational attainment later in life (all \( p < .05 \)).

Kwak et al. (2009). Fitness and AP
Cross-sectional / CRF, mother’s education for SES, family structure, parental monitoring, sex, pubertal phase, and sum of skinfolds / —
232 / 15–16 years / Sweden
Aerobic PA was measured with an accelerometer. The average minutes per day spent in light (<3 METs), moderate (3–6 METs), and vigorous (>6 METs) PA.
AP was assessed through 17 school subjects (Swedish, English, Biology, Chemistry, Physics, Mathematics, Social Sciences, History, Geography, Religion, PE, Health, and 5 additional subjects of preference). The sum of grades for the 17 subjects was used.
After controlling for confounding factors, AP was associated with vigorous PA in girls (\( \beta = 0.30, p < .01 \)), which remained after inclusion of CRF (\( \beta = 0.23, p < .05 \)). In boys, AP was associated with pubertal phase (\( \beta = 0.25, p < .05 \)). After inclusion of CRF, it was only associated with CRF (\( \beta = 0.25, p < .05 \)).

Stroth et al. (2009). Fitness, acute exercise, and executive control
Interventional (controlled cross-over study) / Nothing / 20 min
35 higher- and lower-f t adolescents / 13–14 years / Germany
20 min of acute aerobic exercise and 20 min of rest, sitting on the cycling ergometer for 20 min in both conditions to keep them as similar as possible.
Eriksen flanker task with event-related potential recordings.
Results provide additional evidence for the beneficial effects of fitness on cognition across the human lifespan. While fitness was associated with reliable effects (\( p < .05 \)), acute exercise did not affect event-related potentials in comparison to rest. This suggests that the long-term effects of PA are more robust than short-term effects after a single bout of exercise.

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<tr>
<th>Authors and variables</th>
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<th>Physical fitness measures</th>
<th>CP and AP measures</th>
<th>Results</th>
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<tbody>
<tr>
<td>Travlos (2010). High intensity PE classes and CP</td>
<td>Interventional / Nothing / 4 PE classes</td>
<td>48 / 13–15 years / Greece</td>
<td>Intervention task: an interval aerobic run was employed to increase PA during four PE classes that met at different times during the school day.</td>
<td>A 2-min mathematics task</td>
<td>The intense interval aerobic run significantly affected numeric speed and accuracy of simple addition problems (all p &lt; .05). Students who attended the 1st, 3rd, and 5th hour of the daily classes had significantly higher AP, while the AP of students who attended the 6th-hour PE class was decreased.</td>
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<td>Welk et al. (2010). Fitness and AP</td>
<td>Cross-sectional / SES, minority status, and school size / 2007–2008</td>
<td>36,835 / 6–18 years / USA</td>
<td>CRF (PACER) and BMI.</td>
<td>AP data from the Texas Education Agency (TAKS).</td>
<td>Mixed-model regression analyses revealed modest associations between fitness and AP after controlling for confounders. The effects of fitness on AP were positive but small. A separate logistic regression analysis indicated that higher fitness rates increased the odds of schools achieving exemplary/recognised school status.</td>
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<tr>
<td>Ruiz et al. (2010). PA, fitness, weight status, and CP</td>
<td>Cross-sectional / sex, age, pubertal status, SES, family structure, CRF, strength, and BMI / 2000–2002</td>
<td>1820 / 13–18,5 years / Spain</td>
<td>Self-reported participation in physical sport activity during leisure time. CRF (PACER), muscular strength (dynamometer and standing long jump test), and BMI.</td>
<td>CP (Verbal, numeric and reasoning abilities, and an overall score) was measured by the Spanish version of the SRA-Test of Educational Ability.</td>
<td>Participation in physical sports activities during leisure time was associated with better CP (p &lt; .001), independent of potential confounders (CRF and BMI). CRF was not associated with CP. Neither upper body nor lower body muscular strength was associated with CP. CP was similar across weight status categories.</td>
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<td>Study</td>
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<td>Morales et al. (2011)</td>
<td>Cross-sectional / Perceptual-motor performance, and AP</td>
<td>487 / 2 groups: 9–12 years and 13–16 years / Spain</td>
<td>9–16 years: 2 groups: 9–12 years and 13–16 years / Spain</td>
<td>Perceptual-motor skills (fine motor skills: tower of cubes; gross motor skills: target throwing). Two subtests from BADYG to assess cognitive skills (mathematics skills and oral skills).</td>
<td>Tower of cubes (fine motor skills) and age were predictors of linguistic skills and mathematics skills in adolescents ($r^2 = 0.45$). Thus, this study suggests that enhanced motor skills are associated with better AP.</td>
</tr>
<tr>
<td>London and Castrechini (2011)</td>
<td>Longitudinal / Fitness and AP</td>
<td>1325 / Grade 4–7 (9–13 years) / USA 1410 / Grade 6–9 (12–15 years) / USA</td>
<td>2 cohorts of students:</td>
<td>CRF (PACER), body composition, abdominal strength and endurance, trunk extensor strength and endurance, upper body strength and endurance, and flexibility.</td>
<td>Comparing those who are persistently fit to those who are unfit, authors find disparities in both mathematics and English language arts test scores ($p &lt; .05$). These AP disparities begin even before students begin fitness testing in Grade 5 and are larger for girls and Latinos. Overall fitness is a better predictor of AP than BMI. SES acts as a buffer for those who have poor fitness but strong AP.</td>
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<tr>
<td>Chen et al. (2013)</td>
<td>Longitudinal / Fitness and AP</td>
<td>669 / 7–9th grade (14.6 years) / Taiwan</td>
<td>669 / 7–9th grade run / Taiwan</td>
<td>CRF (1600 boys/800 girls-meter run), sit-and-reach flexibility, bent-leg curl-ups (test abdominal muscle strength and endurance during 1 minute), and BMI.</td>
<td>The results showed that improvement in CRF ($p &lt; .01$), but not muscular endurance or flexibility, is significantly related to greater AP. A weak and non-significant AP-BMI relationship was seen.</td>
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<tr>
<td>Authors and variables</td>
<td>Study design / Confounders / Duration</td>
<td>Sample / age/ Country</td>
<td>Physical fitness measures</td>
<td>CP and AP measures</td>
<td>Results</td>
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<tr>
<td>Kantomaa et al. (2013). PA, obesity, motor function, and AP</td>
<td>Longitudinal / Self-reported MVPA at age 16 years, CRF, self reported BMI, early academic impairment, sex, mother’s highest level of education when the adolescent was 16 years old / 8 years</td>
<td>8.061 / 8–16 years / Finland</td>
<td>Parent-reported motor function (gross and fine motor skills) at age 8 years.</td>
<td>GPA at age 16 years, calculated as a measure of: mother tongue (in most cases Finnish or Swedish), first foreign language (started at Grade 3), second foreign language (started at Grade 7), mathematics, biology, geography, physics, chemistry, religion or ethics, history, music, visual arts, PE, crafts and home economics.</td>
<td>Compromised motor function in childhood predicted lower levels of PA, poor CRF, and higher levels of obesity in adolescence (p &lt; .01). Furthermore, higher levels of PA were associated with a higher GPA, and obesity with a lower GPA in adolescence (p &lt; .01). Compromised motor function had a negative indirect effect on GPA via lower levels of PA and obesity, but not via CRF. Thus, PA and obesity may mediate the association between childhood motor function and adolescents’ AP.</td>
</tr>
<tr>
<td>Bass et al. (2013). Fitness and AP</td>
<td>Cross-sectional / Age and participation in the National School Lunch Programme as indicator of SES / —</td>
<td>838 / 13 years / USA</td>
<td>CRF (PACER). Muscular strength and muscular endurance were assessed using the push-up test and one-minute curl-up test, respectively. Sit and reach was used for flexibility. For body composition, BMI and body fat percentage using a bioelectrical impedance analyser were used.</td>
<td>The Illinois Standardised Achievement Test was used to assess AP in reading and mathematics.</td>
<td>The largest correlations were seen for CRF and muscular endurance (ranging from 0.12 to 0.27, all p &lt; .05). Boys in the Healthy Fitness Zone for CRF or muscular endurance were 2.5–3 times more likely to pass their mathematics or reading exams. Girls in the Healthy Fitness Zone for CRF were approximately 2–4 times as likely to meet or exceed reading and mathematics test standards, controlling for SES and age.</td>
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</table>
There were no significant differences between fitness groups for mathematics and English in Grade 3 students. Grade 6 and Grade 9 students with high fitness scored significantly better on mathematics and Social Studies tests compared with less fit students ($p < .05$). Muscular strength and muscular endurance were associated with AP in all grades.

Fit participants had faster reaction times in the exercise condition in comparison with the rest condition. The results suggest that fitness and acute exercise may enhance CP by increasing functionality of the attentional system in adolescence. This study highlights the importance of intervention programmes providing PA for adolescents, which may improve attention and CP at school and in everyday life.
Table 3. Continued.

<table>
<thead>
<tr>
<th>Authors and variables</th>
<th>Study design / Confounders / Duration</th>
<th>Sample / Country</th>
<th>Physical fitness measures</th>
<th>CP and AP measures</th>
<th>Results</th>
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<tr>
<td>Ardoy et al. (2014). PE class, fitness, CP, and AP</td>
<td>Intervention / Sex, sexual maturation, attendance and baseline values of the dependent variable studied as covariates / 4 months</td>
<td>67 / 13 years / Spain</td>
<td>Adolescents in the CG (control group) received the usual PE sessions (55 min sessions twice per week). Adolescents in the EG1 (experimental group 1) had 4 PE sessions per week, with the same aims, contents and pedagogical strategies as the sessions taken by CG. Adolescents in the EG2 received four PE sessions per week of high intensity. The time devoted to the rest of academic subjects was the same for the three groups. Additionally, CRF (PACER), muscular strength (standing long jump test), and speed-agility (4 × 10-m shuttle run test) were assessed.</td>
<td>CP was assessed by the medium version of the Spanish Overall and Factorial Intelligence Test (IGF-M) (nonverbal and verbal abilities, abstract reasoning, spatial ability, verbal reasoning and numerical ability). AP was assessed by grades in mathematics, Spanish Language, Foreign Language-English, Social Sciences, Natural Sciences, Technology, Plastic-Visual Education and Music, average score from all subjects (includes PE), and average score from all subjects excluding PE.</td>
<td>All CP indicators improved significantly in adolescents from the EG2, compared with those from the CG and EG1 (all p &lt; .001), and verbal reasoning (p = .02). No difference between CG and EG1 in CP. Adolescents from the EG2 had an improved average AP (a score including all the subjects) compared with the CG and the EG1 (p &lt; .001). The differences were significant for mathematics (p = .02) and other subjects, including Technology (p &lt; .001), Natural Sciences (p &lt; .001), and PE (p &lt; .001). AP indicators improved in most of adolescents in EG2 (average for all school subjects = 96% and = 78% when excluding PE). Additional analyses showed that improvements in speed-agility and CRF were correlated with improvements in CP. No associations were observed between changes in fitness and changes in AP.</td>
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<tr>
<td>Study (Year)</td>
<td>Design Type / Variables</td>
<td>Sample Size / Grade Range / Country</td>
<td>Measures / Time Periods</td>
<td>Findings / Effects</td>
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<tr>
<td>Bezold et al. (2014)</td>
<td>Longitudinal / Race and/or ethnicity, language spoken at home, days absent from school, student household poverty, National School Lunch Program, and obesity status / Between 2006–2007 and 2011–2012</td>
<td>83,111 / K-12 (6–18 years) / USA</td>
<td>CRF (PACER), push up, and curl-up tests. For each student, the change in fitness was calculated for three periods: Grade 5–6, Grade 6–7, Grade 7–8.</td>
<td>New York State standardised assessments in English Language Arts and mathematics. Raw scores were used to calculate grade-specific percentile scores separately for mathematics and English Language Arts for each year of data (2006–2007 to 2010–2011), mathematics and English Language Arts percentiles for each student were summed, and a new grade-specific percentile was calculated based on the sum. For girls and boys, a substantial increase in fitness from the previous year resulted in a greater improvement in academic ranking than was seen in the reference group (girls: 0.36 greater percentile point improvement, 95% CI [0.09, 0.63]; boys: 0.38 greater percentile point improvement, 95% CI [0.09, 0.66]). A substantial decrease in fitness was associated with a decrease in AP in both boys and girls. Effects of fitness on AP were stronger in high-poverty boys and girls than in low-poverty boys and girls.</td>
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<tr>
<td>Janak et al. (2014)</td>
<td>Cross-sectional / SES, grade category stratified by sex / 2008–2009</td>
<td>2,550,144 / Grades 3–12 (8–18 years) / USA</td>
<td>CRF (PACER and the 1-mile run) and BMI</td>
<td>TAKS subject material included English language arts, reading, writing, mathematics, science, and social studies with content varying by grade level. This was the first study to describe and analyse this association by geopolitical regions. The prevalence of students meeting the TAKS standard was significantly higher in the highest fitness category for BMI and CRF compared to all other categories, regardless of sex or grade category. Linear modelling suggested a 5% increase in the prevalence of students meeting healthy BMI and CRF standards would result in a 2.25% and 0.65% increase in the prevalence of students meeting the TAKS standard.</td>
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<td>Authors and variables</td>
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<td>Esteban-Cornejo et al. (2014a). Fitness and AP</td>
<td>Cross-sectional / 2011–2012</td>
<td>sex, age, city, pubertal status, maternal education, fitness, and fatness / Spain</td>
<td>2.038 / 6–18 years</td>
<td>CRF (PACER), Motor ability (4 × 10-m shuttle run test). Muscular strength (z-score with handgrip strength and standing long jump test).</td>
<td>AP assessed through school records using 4 indicators: mathematics, Language, an average of mathematics and Language, and grade point average score.</td>
</tr>
<tr>
<td>Sardinha et al. (2014). Fitness, fatness, and AP</td>
<td>Cross-sectional / 2009–2011</td>
<td>Gender, weight status, CRF and different cohorts / Portugal</td>
<td>1531 / 12–14 years</td>
<td>CRF (PACER). Participants were classified as fit and unfit. Weight status (BMI): Participants were classified into normal weight and overweight or obese, according to the International Obesity Task Force.</td>
<td>AP measured using the marks students, at the end of their academic year, in mathematics, language (Portuguese), foreign language (English), and sciences.</td>
</tr>
<tr>
<td>Soga et al. (2015). Executive function and acute moderate aerobic exercise</td>
<td>Interventional / 2015–2016</td>
<td>Nothing / Japan</td>
<td>55 /15–16 years</td>
<td>2 experiments, both in separate sessions, with the same testing model: Experiment 1: n = 28; walking on a treadmill at 60% maximal heart rate. Experiment 2: n = 27; walking on a treadmill at 70% maximal heart rate.</td>
<td>A modified flanker task and a modified n-back task to assess inhibitory control and working memory before, during, and after walking on a treadmill at moderate intensity.</td>
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</table>

Note: CRF = Cardiorespiratory Fitness. PE = Physical Education. PA = Physical Activity. SES = Socioeconomic Status. CP = Cognitive Performance. AP = Academic Performance. BMI = Body Mass Index. MVPA = Moderate to Vigorous Physical Activity. GPA = Grade-point Average. EEG = Electroencephalogram. PACER = Progressive Aerobic Capacity Endurance Run. TAKS = Texas Essential Knowledge and Skills.
et al., 2009; London & Castrechini, 2011; Ruiz et al., 2010; Sardinha et al., 2014; Soga et al., 2015; Stroth et al., 2009; Travlos, 2010; Welk et al., 2010), 9 studied muscular strength (Aberg et al., 2009; Ardoy et al., 2014; Bass et al., 2013; Bezold et al., 2014; Chen et al., 2013; Coe et al., 2013; Esteban-Cornejo et al., 2014a; London & Castrechini, 2011; Ruiz et al., 2010), 2 speed-agility (Ardoy et al., 2014; Esteban-Cornejo et al., 2014a), 2 motor coordination (Budde et al., 2008; Planinsec & Pisot, 2006), 2 perceptual-motor skill (Kantomaa et al., 2013; Morales et al., 2011); 4 included flexibility (Bass et al., 2013; Chen et al., 2013; Coe et al., 2013; London & Castrechini, 2011), 8 added fatness (Bass et al., 2013; Chen et al., 2013; Coe et al., 2013; Janak et al., 2014; London & Castrechini, 2011; Ruiz et al., 2010; Sardinha et al., 2014; Welk et al., 2010), and 1 studied MVPA measured with accelerometers, analysing the mediation of CRF (Kwak et al., 2009). To evaluate CRF, 11 studies used the 20-m shuttle run test (PACER) (Ardoy et al., 2014; Bass et al., 2013; Bezold et al., 2014; Chen et al., 2013; Coe et al., 2013; Esteban-Cornejo et al., 2014a; Janak et al., 2014; London & Castrechini, 2011; Ruiz et al., 2010; Sardinha et al., 2014; Welk et al., 2010), 4 used ergometer cycling (Aberg et al., 2009; Hogan et al., 2013; Kwak et al., 2009; Stroth et al., 2009), 1 used an intense interval aerobic run (Travlos, 2010), and another used a walk on a treadmill at moderate intensity (Soga et al., 2015). To assess muscular strength, the most widely used measures were the curl up test (Bass et al., 2013; Bezold et al., 2014; Chen et al., 2013; Coe et al., 2013; London & Castrechini, 2011), the push up (Bass et al., 2013; Bezold et al., 2014; Coe et al., 2013), and manual dynamometer and the standing long jump test (Esteban-Cornejo et al., 2014a; Ruiz et al., 2010). Speed-agility was assessed with the 4 × 10-m shuttle run test (Ardoy et al., 2014; Esteban-Cornejo et al., 2014a). Motor coordination was evaluated with specific tests (Planinsec & Pisot, 2006) or with exercises of bilateral coordinative skills for short periods of time (Budde et al., 2008). Perceptual-motor skills were performed through fine and gross motor skills (Kantomaa et al., 2013; Morales et al., 2011). With regard to flexibility, the 4 studies used sit-and-reach test (Bass et al., 2013; Chen et al., 2013; Coe et al., 2013; London & Castrechini, 2011), the push up (Bass et al., 2013; Bezold et al., 2014; Coe et al., 2013), and manual dynamometer and the standing long jump test (Esteban-Cornejo et al., 2014a; Ruiz et al., 2010). Speed-agility was assessed with the 4 × 10-m shuttle run test (Ardoy et al., 2014; Esteban-Cornejo et al., 2014a). Motor coordination was evaluated with specific tests (Planinsec & Pisot, 2006) or with exercises of bilateral coordinative skills for short periods of time (Budde et al., 2008). Perceptual-motor skills were performed through fine and gross motor skills (Kantomaa et al., 2013; Morales et al., 2011). With regard to flexibility, the 4 studies used sit-and-reach test (Bass et al., 2013; Chen et al., 2013; Coe et al., 2013; London & Castrechini, 2011). Finally, fatness was mostly assessed on the basis of BMI (Bass et al., 2013; Chen et al., 2013; Coe et al., 2013; Janak et al., 2014; London & Castrechini, 2011; Ruiz et al., 2010; Sardinha et al., 2014; Welk et al., 2010).

A wide variety of tests of general intelligence, neuropsychology capacity, verbal capacity, visual perception, mathematical ability, inhibitory control, or working memory (Aberg et al., 2009; Ardoy et al., 2014; Budde et al., 2008; Hogan et al., 2013; Morales et al., 2011; Planinsec & Pisot, 2006; Ruiz et al., 2010; Soga et al., 2015; Stroth et al., 2009; Travlos, 2010) were used to assess CP. Indirect tests were also used: that is, questionnaires or validated cognitive tests (Aberg et al., 2009; Ardoy et al., 2014; Budde et al., 2008; Morales et al., 2011; Planinsec & Pisot, 2006; Ruiz et al., 2010; Soga et al., 2015; Stroth et al., 2009; Travlos, 2010) and brain function direct tests, i.e., electroencephalographic (EEG) (Hogan et al., 2013; Soga et al., 2015; Stroth et al., 2009). However, AP assessment shows fewer dispersion measures, and most of the studies use average of numeric scores in different academic subjects, mainly mathematics and language scores (Ardoy et al., 2014; Bass et al., 2013; Bezold et al., 2014; Chen et al., 2013; Coe et al., 2013; Esteban-Cornejo et al., 2014a; Janak et al., 2014; Kantomaa et al., 2013; Kwak et al., 2009; London & Castrechini, 2011; Sardinha et al., 2014; Welk et al., 2010).
Physical fitness and cognitive performance

Among the 10 studies that examined the association between physical fitness and CP (Aberg et al., 2009; Ardoy et al., 2014; Budde et al., 2008; Hogan et al., 2013; Morales et al., 2011; Planinsec & Pisot, 2006; Ruiz et al., 2010; Soga et al., 2015; Stroth et al., 2009; Travlos, 2010), 1 was a longitudinal study (Aberg et al., 2009), 6 were interventional (Ardoy et al., 2014; Budde et al., 2008; Hogan et al., 2013; Soga et al., 2015; Stroth et al., 2009; Travlos, 2010), and 3 were cross-sectional studies (Morales et al., 2011; Planinsec & Pisot, 2006; Ruiz et al., 2010). The first study showed that improvement in CRF between 15 and 18 years predicts CP at the age of 18; however, this effect was not found in the case of muscular strength (Aberg et al., 2009). Among the interventional studies, it was found that improvement in PE class intensity, through interval aerobic runs, has a positive influence on numeric speed and on solving simple mathematics problems (Travlos, 2010). Ardoy et al. came to a similar conclusion with the above effect after an increase in the intensity and number of PE classes and after improvements in speed-agility and CRF (Ardoy et al., 2014). A further 2 intervention studies showed a strong positive effect on CP after 10 minutes of coordination exercise (Budde et al., 2008) and 20 minutes of aerobic moderate exercise (Hogan et al., 2013). Nevertheless, 2 similar studies, based on 13 (Soga et al., 2015) or 20 (Stroth et al., 2009) minutes of moderate aerobic exercise, did not achieve significant effect. Finally, while 2 cross-sectional studies did show a positive relation between physical fitness and CP (Morales et al., 2011; Planinsec & Pisot, 2006), a further study did not find a significant association (Ruiz et al., 2010).

Physical fitness and academic performance

A total of 12 studies examined the association between physical fitness and AP (Ardoy et al., 2014; Bass et al., 2013; Bezold et al., 2014; Chen et al., 2013; Coe et al., 2013; Esteban-Cornejo et al., 2014a; Janak et al., 2014; Kantomaa et al., 2013; Kwak et al., 2009; London & Castrechini, 2011; Sardinha et al., 2014; Welk et al., 2010). Of these studies, 4 used a longitudinal design (Bezold et al., 2014; Chen et al., 2013; Kantomaa et al., 2013; London & Castrechini, 2011), 1 was interventional (Ardoy et al., 2014), and 7 were cross-sectional studies (Bass et al., 2013; Coe et al., 2013; Esteban-Cornejo et al., 2014a; Janak et al., 2014; Kwak et al., 2009; Sardinha et al., 2014; Welk et al., 2010). Of these studies, 4 used a longitudinal design (Bezold et al., 2014; Chen et al., 2013; Kantomaa et al., 2013; London & Castrechini, 2011), 1 was interventional (Ardoy et al., 2014), and 7 were cross-sectional studies (Bass et al., 2013; Coe et al., 2013; Esteban-Cornejo et al., 2014a; Janak et al., 2014; Kwak et al., 2009; Sardinha et al., 2014; Welk et al., 2010). Of these studies, 4 used a longitudinal design (Bezold et al., 2014; Chen et al., 2013; Kantomaa et al., 2013; London & Castrechini, 2011), 1 was interventional (Ardoy et al., 2014), and 7 were cross-sectional studies (Bass et al., 2013; Coe et al., 2013; Esteban-Cornejo et al., 2014a; Janak et al., 2014; Kwak et al., 2009; Sardinha et al., 2014; Welk et al., 2010). Of these studies, 4 used a longitudinal design (Bezold et al., 2014; Chen et al., 2013; Kantomaa et al., 2013; London & Castrechini, 2011), 1 was interventional (Ardoy et al., 2014), and 7 were cross-sectional studies (Bass et al., 2013; Coe et al., 2013; Esteban-Cornejo et al., 2014a; Janak et al., 2014; Kwak et al., 2009; Sardinha et al., 2014; Welk et al., 2010). Of these studies, 4 used a longitudinal design (Bezold et al., 2014; Chen et al., 2013; Kantomaa et al., 2013; London & Castrechini, 2011), 1 was interventional (Ardoy et al., 2014), and 7 were cross-sectional studies (Bass et al., 2013; Coe et al., 2013; Esteban-Cornejo et al., 2014a; Janak et al., 2014; Kwak et al., 2009; Sardinha et al., 2014; Welk et al., 2010). With regard to the first group of studies, London and Castrechini (2011) found that fit young people achieve better mathematics and language scores than those who are unfit. Two studies revealed that an increase in fitness from childhood has a significant influence, with better AP for adolescence (Bezold et al., 2014; Kantomaa et al., 2013). However, a separate analysis of the influence of each fitness component showed that only CRF was related with higher AP (Chen et al., 2013). With regard to the interventional study, Ardoy et al. (2014) showed that the raise of number and intensity of PE weekly classes, positively affects AP. Nevertheless, for these authors, improvements in CRF, muscular strength or speed-agility, did not lead to a significantly increased AP (Ardoy et al., 2014). Finally, 4 of the 7 cross-sectional studies revealed an association between CRF and AP after adjusting for potential confounders (Janak et al., 2014; Kwak et al., 2009; Sardinha et al., 2014; Welk et al., 2010), although in 1 of them, the association was weak (Welk et al., 2010). In another cross-sectional study, Coe et al. (2013) showed a significant
association between higher fitness scores (Healthy Fitness Zone of Fitnessgram) and AP. A further study with the same design, but controlling by SES and age, showed that CRF was positively associated with AP in mathematics and reading, mostly in girls rather than boys (Bass et al., 2013). Esteban-Cornejo et al. (2014a), in another cross-sectional study, found positive associations of CRF and motor-agility with AP, although this association was not significant with regard to the muscular strength.

**Discussion**

This systematic review has researched the association of different components of physical fitness with CP and AP in adolescents. Studies from 2005 to January 2015 were obtained from 4 databases. A total of 21 articles met the inclusion criteria: 10 studies used a cross-sectional design, 6 were intervention studies, 4 were longitudinal, and only 1 study included a double design that was cross-sectional and longitudinal. The physical fitness variables used were CRF, muscular strength, speed-agility, motor coordination, perceptual-motor skill, flexibility, and fatness. Of the 21 studies, 62% used confounders. The most controlled confounder was SES. Fatness was also widely used, measured through the sum of skinfold, BMI, or waist circumference. Pubertal status, sex, or age were also included as confounders. A majority of the studies showed a positive association of physical fitness with CP and AP. Eight studies showed association between physical fitness and CP, and only 2 studies found no association (Ruiz et al., 2010; Soga et al., 2015). A better physical fitness was associated with higher AP in 11 studies (Bass et al., 2013; Bezold et al., 2014; Chen et al., 2013; Coe et al., 2013; Esteban-Cornejo et al., 2014a; Janak et al., 2014; Kantoma et al., 2013; Kwak et al., 2009; London & Castrechini, 2011; Sardinha et al., 2014; Welk et al., 2010), while 1 study found no relation (Ardoy et al., 2014). CRF, speed-agility, motor coordination, and perceptual-motor skill are the components that are mostly associated with CP and AP in adolescents, while the relationship with regard to muscular strength and flexibility has been less studied and the results are unclear.

These results suggest that physical fitness can be a factor with potential for cognitive and academic development during adolescence. This is especially so because physical fitness contributes to the acceleration of psychomotor development, decreases anxiety and stress, and increases self-esteem, all of which are closely related with AP (Tremblay, Inman, & Willms, 2000). Likewise, physical fitness could improve the student’s behaviour in a learning context and, consequently, may increase the potential for better concentration and AP (Singh et al., 2012). Thus, developing programmes that are based on improving fitness could promote academic success for students in this age range (Coe et al., 2013). Some factors that may positively influence physical fitness levels could be motivation, adherence to PA through the use of new technologies as heart rate monitors, proposals of extracurricular PA, parental support outside the school context, and increased intensity of PE classes.

The detailed analysis of the influence of each physical fitness component has found that CRF is the most studied component and has the greatest influence on the CP and AP. To evaluate CRF, 11 studies used the 20-m shuttle run test (PACER) (Ardoy et al., 2014; Bass et al., 2013; Bezold et al., 2014; Chen et al., 2013; Coe et al., 2013; Esteban-Cornejo et al., 2014a; Janak et al., 2014; London & Castrechini, 2011; Ruiz et al., 2010; Sardinha et al., 2014; Welk et al., 2010). Most of these studies showed a positive association of CRF on
CP (Aberg et al., 2009; Hogan et al., 2013; Janak et al., 2014; Stroth et al., 2009; Travlos, 2010) and AP (Bezold et al., 2014; Chen et al., 2013; Coe et al., 2013; Janak et al., 2014; Kantomaa et al., 2013; Kwak et al., 2009; London & Castrechini, 2011; Sardinha et al., 2014; Welk et al., 2010), 2 studies found no significant effects (Ardoy et al., 2014; Ruiz et al., 2010), but none revealed a negative association. The study of Aberg et al. (2009), carried out with 1.221.727 Swedish male adolescents, established that improvements in CRF between ages 15 and 18 years predicted global intelligence at age 18. Furthermore, physically active lessons of moderate to vigorous or high intensity can provide wide benefits for CP and AP (Donnelly & Lambourne, 2011; Mullender-Wijnsma et al., 2015).

Several mechanisms have been proposed to explain the association of CRF with CP and AP. First, CRF stimulates the hippocampus Fndc5 gene expression through a PGC-1α /Errα transcriptional complex. This elevated Fndc5 gene expression, in turn, stimulates BDNF gene expression. BDNF is the master regulator of nerve cell survival, differentiation, and plasticity in the brain, which improves cognitive function (Chang & Etnier, 2015; Noakes & Spedding, 2012; Piepmeier & Etnier, 2015; Wrann et al., 2013). Second, CRF improves the microstructure of the white matter of the brain, increasing the speed and efficiency of neuronal activity (Chaddock-Heyman et al., 2014a). Third, CRF increases angiogenesis. This phenomenon improves capillary density and brain vascularisation, affecting cognition (Adkins, Boychuk, Remple, & Kleim, 2006). Finally, CRF is related with higher P3 event-related brain potential amplitude and lower P3 latency, which reflects a better ability to modulate neuroelectric indices of cognitive control (Hillman et al., 2009). These processes are involved in cognitive control, specifically in inhibition, cognitive flexibility, and working memory, which provide the basis for a better AP (Diamond, 2000; Haapala, 2013).

With regard to muscular strength, 2 cross-sectional studies showed no association with CP (Ruiz et al., 2010) and AP (Esteban-Cornejo et al., 2014a). An intervention study showed that improvements in muscular strength did not positively affect CP and AP (Ardoy et al., 2014). Neither did improvements in muscular strength between ages 15 and 18 predict intelligence at age 18 (Aberg et al., 2009). In contrast, Coe et al. (2013) reported that muscular strength was associated with AP between 8 and 15 years of age. The longitudinal study of Bezold et al. (2014) also revealed that the combined improvement of muscular strength and CRF was positively associated with AP, and a decrease in the levels of these components was associated with a decrease in AP. This disagreement in the results can be explained by several factors: (1) the possible collateral influence of improvements on other fitness components (Bezold et al., 2014), (2) using different tests to assess muscular strength (Torrijos-Niño et al., 2014), (3) the different sample sizes (Chen et al., 2013), or (4) the controlled confounders (Chen et al., 2013; Coe et al., 2013; Esteban-Cornejo et al., 2014a). Therefore, it is necessary for future studies to continue to analyse the influence of muscular strength and to determine the causes of these divergent results.

On the other hand, this systematic review has found that speed-agility can be a potential predictor of CP (Ardoy et al., 2014) and AP (Esteban-Cornejo et al., 2014a). The study by Niederer et al. (2011) showed that from the age of 5–6 years, speed-agility is associated with a better memory. Several studies have found an association of motor coordination with intelligence (Planinsec & Pisot, 2006), with concentration, and with attention (Budde et al., 2008). Positive associations of fine-motor skill with linguistic and mathematical skill have been also found (Morales et al., 2011). In addition, gross-motor development predicts a significant improvement in memory some years later (Piek, Dawson, Smith, &
Gasson, 2008). At the same time, disorders in coordination and motor skills have been associated with cognitive and learning deficits (Haapala, 2013).

Various biological and neurological mechanisms could explain the effect of speed-agility, motor coordination, and perceptual-motor skill on CP and AP. First, biological maturity may confound the relationship between motor skills and CP (Haapala, 2013), which means that more mature young people could have a more advanced neuromuscular system and, therefore, achieve better scores in motor tests. In fact, in this review some studies show the importance of pubertal maturation, adding this as a confounder (Ardoy et al., 2014; Esteban-Cornejo et al., 2014a). Second, improvements in speed-agility and coordination might lead to a pre-activation of the neocerebellum and dorsolateral prefrontal cortex (Diamond, 2000), leading to improvements in attention (Budde et al., 2008; Kwak et al., 2009). Third, high levels of speed-agility, coordination, and motor skill are highly associated with the neuromotor system. This can improve conduction speed of the nerve impulse and have an influence on the brain’s processing speed (Esteban-Cornejo et al., 2014a; Torrijos-Niño et al., 2014). Fourth, these variables could improve the spinal cord function, causing synaptogenesis and an increase in the number of synapses, increasing the BDNF and the reorganisation of movement representations within the motor cortex (Adkins et al., 2006). This combined set of neural changes could positively impact on CP (Adkins et al., 2006) and, subsequently, on AP (Esteban-Cornejo et al., 2014a; Torrijos-Niño et al., 2014).

Studies that examined the association of flexibility with CP and AP used the sit-and-reach test to assess this component (Bass et al., 2013; Chen et al., 2013; Coe et al., 2013; London & Castrechini, 2011). London and Castrechini (2011) showed that general physical fitness—including flexibility—was a better predictor of AP than obesity. However, flexibility was not independently associated with CP and AP in other studies in this review (Bass et al., 2013; Chen et al., 2013; Coe et al., 2013). The lack of relationship of flexibility with CP and AP could be because this type of exercise does not produce sufficient stimulus on the nervous system, nor does it increase brain blood flow. Nevertheless, these findings contrast with other previous research on scholar age, which showed an association between flexibility and AP in 7961 Australian students (Dwyer, Sallis, Blizzard, Lazzarus, & Dean, 2001) and in 254,743 American students (Van Dusen et al., 2011), perhaps due to sample size, participant age, or because more flexible children could also have more CRF, speed-agility, or motor coordination, components that affect CP and AP. Future studies should consider both findings and should continue to explore the effect of flexibility at the cognitive level.

The influence of body composition on CP and AP is another interesting point in this review. Two studies found no association of fatness with CP (Ruiz et al., 2010) and AP (Chen et al., 2013). In contrast, 2 other studies showed a negative relationship between fatness and AP (Kantomaa et al., 2013; Sardinha et al., 2014). Along the same lines, it has been demonstrated that young people with a healthy diet and who do more exercise weekly achieve better AP (Shi, Tubb, Fingers, Chen, & Caffrey, 2013). Another cross-sectional study showed that independent and combined neonatal and current body composition may influence AP (Esteban-Cornejo et al., 2015b). The diversity of results regarding this association could be explained by the lack of control of some of the variables related to the characteristics of participants or by other psychosocial variables (Donnelly & Lambourne, 2011). Despite these findings, it has been shown that physical fitness is a better predictor of AP than fatness (London & Castrechini, 2011; Torrijos-Niño et al., 2014).
This systematic review has noted that 62% of the studies analysed used confounders. The confounders most used were SES through maternal education (Esteban-Cornejo et al., 2014a; Kantomaa et al., 2013; Kwak et al., 2009), educational level of both parents (Aberg et al., 2009; Chen et al., 2013; Ruiz et al., 2010), participation in the National School Lunch Programme (Bass et al., 2013; Bezold et al., 2014; Janak et al., 2014; Welk et al., 2010), and indicators of fatness, especially BMI (Bezold et al., 2014; Esteban-Cornejo et al., 2014a; Kantomaa et al., 2013; Ruiz et al., 2010; Sardinha et al., 2014). Previous studies have shown that there is an influence of SES (Coe et al., 2013; London & Castrechini, 2011) and fatness (Sardinha et al., 2014; Torrijos-Niño et al., 2014) on cognition.

On the other hand, sex (Ardoy et al., 2014; Chen et al., 2013; Esteban-Cornejo et al., 2014a; Janak et al., 2014; Kantomaa et al., 2013; Kwak et al., 2009; Ruiz et al., 2010; Sardinha et al., 2014) appears as another important confounder. Although 2 studies show no differences by sex (Morales et al., 2011; Ruiz et al., 2010), other studies did find differences. The majority of studies found a higher fitness effect on AP in girls than in boys (Bass et al., 2013; Kwak et al., 2009; London & Castrechini, 2011). The sex effect in another study also suggests that the association between more time spent in PA and higher CP is more frequently found in adolescent girls than in boys (Martínez-Gómez et al., 2011). However, we are aware of only one study that associates more vigorous PA with better AP in males (So, 2012). This trend favouring girls could be explained by the dose-response effect (Martínez-Gómez et al., 2011)—that is, boys are more active than girls (Verloigne et al., 2012) and, therefore, the achieved stimulus, due to lower levels of PA, may not be sufficient to produce the same effect on CP in both sexes. Other possible confounders that could affect the association of physical fitness with CP and AP are student household poverty (Bezold et al., 2014), heart rate (Budde et al., 2008), age (Bass et al., 2013; Chen et al., 2013; Esteban-Cornejo et al., 2014a; Ruiz et al., 2010), other fatness indicators (such as sum of skinfolds, waist circumference, or neonatal body composition), pubertal status (Ardoy et al., 2014; Esteban-Cornejo et al., 2014a; Kwak et al., 2009; Ruiz et al., 2010), minority status, school size (Welk et al., 2010), early academic impairment (Kantomaa et al., 2013), time of breastfeeding (Victora et al., 2015), race and/or ethnicity, language spoken at home, days absent from school, or place of birth (Bezold et al., 2014).

The strength of this review is that it has examined the individual and combined associations for CP and AP with regard to the different components of physical fitness. The review covers a period of 10 years and includes peer-reviewed research from 10 different countries. A quality standardised assessment list was used to select the studies. The review included cross-sectional, longitudinal, and interventional studies, and potential confounders were taken into account. On the other hand, this review has also some limitations. For example, we gave equal importance to studies with small sample sizes and studies with larger samples. Other important databases, such as EMBASE, were not included in the current systematic review. Other limitations could be language bias and publication bias (as regards search restrictions and including only published studies). Nevertheless, we have not found in previous systematic reviews and reference lists any relevant study meeting the inclusion criteria of this review in a language other than English. In addition, for the introduction and discussion sections, we take into account the most relevant studies prior to 2005 and previous systematic reviews that include variables studied in this review. Likewise, the review does not include studies that focused on metabolic (i.e., overweight-obesity) or other kinds of diseases (i.e., mental, allergic, or developmental disorders).
addition, some of the effects of the association may be inconsistent due to the influence of inter-components within the same participant. For example, in studies where only a global average score of physical fitness without separate components was used (i.e., London & Castrechini, 2011), there may be a collateral effect of some of them (i.e., CRF, speed-agility, or motor coordination), on components less closely related to the CP and AP (i.e., flexibility), thus diluting the real impact of each component. However, most studies analysed in this review separate by component and do not find an independent association between flexibility and CP or AP (Bass et al., 2013; Chen et al., 2013; Coe et al., 2013). Future studies should consider these independent relationships. Finally, although we have relied on quality tools used by previous studies, the tool used to measure quality is not validated (Castro-Piñero et al., 2010; Ruiz et al., 2009).

**Conclusion**

The present review found a total of 21 articles that analysed the association of physical fitness with CP and AP in adolescents. Ten of these articles focused on CP and 12 on AP (one studied both CP and AP). Most studies showed a positive association of physical fitness with CP and AP: 8 studies showed an association between physical fitness and CP, whereas only 2 studies found no association. Better physical fitness was also associated with better AP in 11 studies, while only 1 study found no relationship. CRF, speed-agility, motor coordination, and perceptual-motor skill are components that are mostly associated with CP and AP in adolescents, while the relationship with regard to muscular strength and flexibility is unclear. Finally, confounders may play a key role in these associations. More research is needed to explain the differential effect of different physical fitness components on CP and AP, to clarify the role of confounders, and to determine the cut-off point in fitness for predicting better CP and AP. Programmes and combined interventions to improve fitness, CP and AP during adolescence should be promoted in political, educational, and family areas.

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